Appendix B. Distribution of Pre-Crash Scenario by System Category–V2V System Primary

Table B1. Target All-Vehicle Crash Data for V2V Systems as Primary Countermeasure

Pre-Crash Scenario	All Crashes	V2V	AV	V2I
No driver present	1,000	-	-	-
Vehicle failure	50,000	-	50,000	-
Control loss/vehicle action	97,000	97,000	-	-
Control loss/no vehicle action	442,000	442,000	-	-
Running red light	226,000	226,000	-	1,000
Running stop sign	42,000	39,000	3,000	3,000
Road edge departure/maneuver	74,000	-	9,000	10,000
Road edge departure/no maneuver	277,000	-	277,000	54,000
Road edge departure/backing	82,000	-	82,000	-
Animal/maneuver	18,000	-	18,000	-
Animal/no maneuver	296,000	-	296,000	-
Pedestrian/maneuver	21,000	-	21,000	8,000
Pedestrian/no maneuver	42,000	-	42,000	5,000
Cyclist/maneuver	21,000	-	21,000	-
Cyclist/no maneuver	29,000	-	29,000	-
Backing into vehicle	129,000	129,000	-	-
Turning/same direction	197,000	197,000	-	-
Parking/same direction	38,000	38,000	-	-
Changing lanes/same direction	334,000	334,000	-	-
Drifting/same lane	105,000	105,000	-	-
Opposite direction/maneuver	9,000	9,000	-	-
Opposite direction/no maneuver	108,000	108,000	-	-
Rear-end/striking maneuver	81,000	81,000	-	-
Rear-end/LVA	22,000	22,000	-	-
Rear-end/LVM	192,000	192,000	-	-
Rear-end/LVD	388,000	388,000	-	-
Rear-end/LVS	910,000	910,000	-	-
LTAP/OD @ signal	195,000	195,000	-	-
Turn right @ signal	30,000	30,000	-	-
LTAP/OD @ non signal	179,000	179,000	-	-
SCP @ non signal	637,000	637,000	-	-
Turn @ non signal	45,000	45,000	-	-
Evasive maneuver/maneuver	12,000	-	-	-
Evasive maneuver/no maneuver	45,000	-	-	-
Rollover	6,000	-	1,000	1,000
Noncollision - No impact	36,000	-	-	-
Object contacted/maneuver	66,000	-	4,000	5,000
Object contacted/no maneuver	82,000	-	82,000	7,000
Hit and run	3,000	-	-	-
Other - Rear-end	1,000	1,000	-	-
Other - Sideswipe	2,000	2,000	-	-
Other - Turn Across Path	1,000	1,000	-	-
Other - Turn Into Path	1,000	1,000	-	-
Other	22,000	-	-	-
	5,595,000	4,409,000	935,000	94,000

Table B2. Target Light-Vehicle Crash Data for V2V Systems as Primary Countermeasure

Pre-Crash Scenario	All Crashes	V2V	AV	V2I
No driver present	1,000	-	-	-
Vehicle failure	45,000	-	45,000	-
Control loss/vehicle action	89,000	89,000	-	-
Control loss/no vehicle action	414,000	414,000	-	-
Running red light	226,000	225,000	-	1,000
Running stop sign	42,000	39,000	2,000	2,000
Road edge departure/maneuver	54,000	-	8,000	9,000
Road edge departure/no maneuver	240,000	-	240,000	48,000
Road edge departure/backing	68,000	-	68,000	-
Animal/maneuver	15,000	-	15,000	-
Animal/no maneuver	285,000	-	285,000	-
Pedestrian/maneuver	19,000	-	19,000	8,000
Pedestrian/no maneuver	39,000	-	39,000	5,000
Cyclist/maneuver	20,000	-	20,000	-
Cyclist/no maneuver	27,000	-	27,000	-
Backing into vehicle	127,000	127,000	-	-
Turning/same direction	195,000	195,000	-	-
Parking/same direction	38,000	38,000	-	-
Changing lanes/same direction	329,000	329,000	-	-
Drifting/same lane	102,000	102,000	-	-
Opposite direction/maneuver	9,000	9,000	-	-
Opposite direction/no maneuver	102,000	102,000	-	-
Rear-end/striking maneuver	80,000	80,000	-	-
Rear-end/LVA	22,000	22,000	-	-
Rear-end/LVM	190,000	190,000	-	-
Rear-end/LVD	384,000	384,000	-	-
Rear-end/LVS	906,000	906,000	-	-
LTAP/OD @ signal	195,000	195,000	-	-
Turn right @ signal	29,000	29,000	-	-
LTAP/OD @ non signal	178,000	178,000	-	-
SCP @ non signal	634,000	634,000	-	-
Turn @ non signal	43,000	43,000	-	-
Evasive maneuver/maneuver	12,000	-	-	-
Evasive maneuver/no maneuver	43,000	-	-	-
Rollover	3,000	-	1,000	1,000
Noncollision - No impact	30,000	-	-	-
Object contacted/maneuver	32,000	-	2,000	3,000
Object contacted/no maneuver	61,000	-	61,000	5,000
Hit and run	3,000	-	-	-
Other - Rear-end	1,000	1,000	-	-
Other - Sideswipe	2,000	2,000	-	-
Other - Turn Across Path	1,000	1,000	-	-
Other - Turn Into Path	1,000	1,000	-	-
Other	21,000	-	-	-
	5,356,000	4,336,000	833,000	81,000

Table B3. Target Heavy-Truck Crash Data for V2V Systems as Primary Countermeasure

Pre-Crash Scenario	All Crashes	V2V	AV	V2I
No driver present	-	-	-	-
Vehicle failure	5,000	-	5,000	-
Control loss/vehicle action	5,000	5,000	-	-
Control loss/no vehicle action	16,000	16,000	-	-
Running red light	9,000	9,000	-	-
Running stop sign	2,000	1,000	-	-
Road edge departure/maneuver	14,000	-	1,000	1,000
Road edge departure/no maneuver	17,000	-	17,000	2,000
Road edge departure/backing	8,000	-	8,000	-
Animal/maneuver	2,000	-	2,000	-
Animal/no maneuver	5,000	-	5,000	-
Pedestrian/maneuver	1,000	-	1,000	-
Pedestrian/no maneuver	1,000	-	1,000	-
Cyclist/maneuver	-	-	-	-
Cyclist/no maneuver	-	-	-	-
Backing into vehicle	19,000	19,000	-	-
Turning/same direction	28,000	28,000	-	-
Parking/same direction	3,000	3,000	-	-
Changing lanes/same direction	49,000	49,000	-	-
Drifting/same lane	20,000	20,000	-	-
Opposite direction/maneuver	1,000	1,000	-	-
Opposite direction/no maneuver	13,000	13,000	-	-
Rear-end/striking maneuver	4,000	4,000	-	-
Rear-end/LVA	1,000	1,000	-	-
Rear-end/LVM	13,000	13,000	-	-
Rear-end/LVD	17,000	17,000	-	-
Rear-end/LVS	29,000	29,000	-	-
LTAP/OD @ signal	5,000	5,000	-	-
Turn right @ signal	3,000	3,000	-	-
LTAP/OD @ non signal	5,000	5,000	-	-
SCP @ non signal	22,000	22,000	-	-
Turn @ non signal	5,000	5,000	-	-
Evasive maneuver/maneuver	1,000	-	-	-
Evasive maneuver/no maneuver	3,000	-	-	-
Rollover	1,000	-	-	-
Noncollision - No impact	11,000	-	-	-
Object contacted/maneuver	19,000	-	-	1,000
Object contacted/no maneuver	17,000	-	17,000	1,000
Hit and run	1,000	-	-	-
Other - Rear-end	-	-	-	-
Other - Sideswipe	-	-	-	-
Other - Turn Across Path	-	-	-	-
Other - Turn Into Path	-	-	-	-
Other	3,000	-	-	-
	375,000	267,000	57,000	5,000

Appendix C. Distribution of Pre-Crash Scenario by System Category–V2I System Primary

Table C1. Target All-Vehicle Crash Data for V2I Systems as Primary Countermeasure

Pre-Crash Scenario	All Crashes	V2I	AV	V2V
No driver present	1,000	-	-	-
Vehicle failure	50,000	-	50,000	-
Control loss/vehicle action	97,000	59,000	-	38,000
Control loss/no vehicle action	442,000	252,000	-	190,000
Running red light	226,000	226,000	-	-
Running stop sign	42,000	42,000	-	-
Road edge departure/maneuver	74,000	10,000	-	-
Road edge departure/no maneuver	277,000	54,000	223,000	-
Road edge departure/backing	82,000	-	82,000	-
Animal/maneuver	18,000	-	18,000	-
Animal/no maneuver	296,000	-	296,000	-
Pedestrian/maneuver	21,000	8,000	13,000	-
Pedestrian/no maneuver	42,000	5,000	37,000	-
Cyclist/maneuver	21,000	-	21,000	-
Cyclist/no maneuver	29,000	-	29,000	-
Backing into vehicle	129,000	-	-	129,000
Turning/same direction	197,000	-	197,000	197,000
Parking/same direction	38,000	-	38,000	38,000
Changing lanes/same direction	334,000	-	334,000	334,000
Drifting/same lane	105,000	-	105,000	105,000
Opposite direction/maneuver	9,000	-	-	9,000
Opposite direction/no maneuver	108,000	-	108,000	108,000
Rear-end/striking maneuver	81,000	-	81,000	81,000
Rear-end/LVA	22,000	-	22,000	22,000
Rear-end/LVM	192,000	-	192,000	192,000
Rear-end/LVD	388,000	-	388,000	388,000
Rear-end/LVS	910,000	-	910,000	910,000
LTAP/OD @ signal	195,000	195,000	-	-
Turn right @ signal	30,000	30,000	-	-
LTAP/OD @ non signal	179,000	108,000	-	71,000
SCP @ non signal	637,000	433,000	-	204,000
Turn @ non signal	45,000	27,000	-	18,000
Evasive maneuver/maneuver	12,000	-	-	-
Evasive maneuver/no maneuver	45,000	-	-	-
Rollover	6,000	1,000	-	-
Noncollision - No impact	36,000	-	-	-
Object contacted/maneuver	66,000	5,000	-	-
Object contacted/no maneuver	82,000	7,000	76,000	-
Hit and run	3,000	-	-	-
Other - Rear-end	1,000	-	1,000	1,000
Other - Sideswipe	2,000	-	2,000	2,000
Other - Turn Across Path	1,000	1,000	-	-
Other - Turn Into Path	1,000	1,000	-	-
Other	22,000	-	-	-
	5,595,000	1,465,000	3,223,000	3,038,000

Table C2. Target Light-Vehicle Crash Data for V2I Systems as Primary Countermeasure

Pre-Crash Scenario	All Crashes	V2I	AV	V2V
No driver present	1,000	-	-	-
Vehicle failure	45,000	-	45,000	-
Control loss/vehicle action	89,000	55,000	-	34,000
Control loss/no vehicle action	414,000	238,000	-	176,000
Running red light	226,000	226,000	-	-
Running stop sign	42,000	42,000	-	-
Road edge departure/maneuver	54,000	9,000	-	-
Road edge departure/no maneuver	240,000	48,000	192,000	-
Road edge departure/backing	68,000	-	68,000	-
Animal/maneuver	15,000	-	15,000	-
Animal/no maneuver	285,000	-	285,000	-
Pedestrian/maneuver	19,000	8,000	11,000	-
Pedestrian/no maneuver	39,000	5,000	35,000	-
Cyclist/maneuver	20,000	-	20,000	-
Cyclist/no maneuver	27,000	-	27,000	-
Backing into vehicle	127,000	-	-	127,000
Turning/same direction	195,000	-	195,000	195,000
Parking/same direction	38,000	-	38,000	38,000
Changing lanes/same direction	329,000	-	329,000	329,000
Drifting/same lane	102,000	-	102,000	102,000
Opposite direction/maneuver	9,000	-	-	9,000
Opposite direction/no maneuver	102,000	-	102,000	102,000
Rear-end/striking maneuver	80,000	-	80,000	80,000
Rear-end/LVA	22,000	-	22,000	22,000
Rear-end/LVM	190,000	-	190,000	190,000
Rear-end/LVD	384,000	-	384,000	384,000
Rear-end/LVS	906,000	-	906,000	906,000
LTAP/OD @ signal	195,000	195,000	-	-
Turn right @ signal	29,000	29,000	-	-
LTAP/OD @ non signal	178,000	108,000	-	70,000
SCP @ non signal	634,000	432,000	-	202,000
Turn @ non signal	43,000	26,000	-	16,000
Evasive maneuver/maneuver	12,000	-	-	-
Evasive maneuver/no maneuver	43,000	-	-	-
Rollover	3,000	1,000	-	-
Noncollision - No impact	30,000	-	-	-
Object contacted/maneuver	32,000	3,000	-	-
Object contacted/no maneuver	61,000	5,000	56,000	-
Hit and run	3,000	-	-	-
Other - Rear-end	1,000	-	1,000	1,000
Other - Sideswipe	2,000	-	2,000	2,000
Other - Turn Across Path	1,000	1,000	-	-
Other - Turn Into Path	1,000	1,000	-	-
Other	21,000	-	-	-
	5,356,000	1,431,000	3,105,000	2,986,000

Table C3. Target Heavy-Truck Crash Data for V2I Systems as Primary Countermeasure

Pre-Crash Scenario	All Crashes	V2I	AV	V2V
No driver present	-	-	-	-
Vehicle failure	5,000	-	5,000	-
Control loss/vehicle action	5,000	3,000	-	2,000
Control loss/no vehicle action	16,000	9,000	-	7,000
Running red light	9,000	9,000	-	-
Running stop sign	2,000	2,000	-	-
Road edge departure/maneuver	14,000	1,000	-	-
Road edge departure/no maneuver	17,000	2,000	15,000	-
Road edge departure/backing	8,000	-	8,000	-
Animal/maneuver	2,000	-	2,000	-
Animal/no maneuver	5,000	-	5,000	-
Pedestrian/maneuver	1,000	-	-	-
Pedestrian/no maneuver	1,000	-	-	-
Cyclist/maneuver	-	-	-	-
Cyclist/no maneuver	-	-	-	-
Backing into vehicle	19,000	-	-	19,000
Turning/same direction	28,000	-	28,000	28,000
Parking/same direction	3,000	-	3,000	3,000
Changing lanes/same direction	49,000	-	49,000	49,000
Drifting/same lane	20,000	-	20,000	20,000
Opposite direction/maneuver	1,000	-	-	1,000
Opposite direction/no maneuver	13,000	-	13,000	13,000
Rear-end/striking maneuver	4,000	-	4,000	4,000
Rear-end/LVA	1,000	-	1,000	1,000
Rear-end/LVM	13,000	-	13,000	13,000
Rear-end/LVD	17,000	-	17,000	17,000
Rear-end/LVS	29,000	-	29,000	29,000
LTAP/OD @ signal	5,000	5,000	-	-
Turn right @ signal	3,000	3,000	-	-
LTAP/OD @ non signal	5,000	3,000	-	2,000
SCP @ non signal	22,000	15,000	-	7,000
Turn @ non signal	5,000	3,000	-	2,000
Evasive maneuver/maneuver	1,000	-	-	-
Evasive maneuver/no maneuver	3,000	-	-	-
Rollover	1,000	-	-	-
Noncollision - No impact	11,000	-	-	-
Object contacted/maneuver	19,000	1,000	-	-
Object contacted/no maneuver	17,000	1,000	16,000	-
Hit and run	1,000	-	-	-
Other - Rear-end	-	-	-	-
Other - Sideswipe	-	-	-	-
Other - Turn Across Path	-	-	-	-
Other - Turn Into Path	-	-	-	-
Other	3,000	-	-	-
	375,000	55,000	229,000	217,000

Appendix D. Distribution of Pre-Crash Scenario by System Category–Combined V2V and V2I System Primary

Table D1. Target All-Vehicle Crash Data for Combined V2V and V2I Systems as Primary Countermeasure

Pre-Crash Scenario	All Crashes	V2V & V2I	AV
No driver present	1,000	-	-
Vehicle failure	50,000	-	50,000
Control loss/vehicle action	97,000	97,000	-
Control loss/no vehicle action	442,000	442,000	-
Running red light	226,000	226,000	-
Running stop sign	42,000	42,000	-
Road edge departure/maneuver	74,000	10,000	-
Road edge departure/no maneuver	277,000	54,000	223,000
Road edge departure/backing	82,000	-	82,000
Animal/maneuver	18,000	-	18,000
Animal/no maneuver	296,000	-	296,000
Pedestrian/maneuver	21,000	8,000	13,000
Pedestrian/no maneuver	42,000	5,000	37,000
Cyclist/maneuver	21,000	-	21,000
Cyclist/no maneuver	29,000	-	29,000
Backing into vehicle	129,000	129,000	-
Turning/same direction	197,000	197,000	-
Parking/same direction	38,000	38,000	-
Changing lanes/same direction	334,000	334,000	-
Drifting/same lane	105,000	105,000	-
Opposite direction/maneuver	9,000	9,000	-
Opposite direction/no maneuver	108,000	108,000	-
Rear-end/striking maneuver	81,000	81,000	-
Rear-end/LVA	22,000	22,000	-
Rear-end/LVM	192,000	192,000	-
Rear-end/LVD	388,000	388,000	-
Rear-end/LVS	910,000	910,000	-
LTAP/OD @ signal	195,000	195,000	-
Turn right @ signal	30,000	30,000	-
LTAP/OD @ non signal	179,000	179,000	-
SCP @ non signal	637,000	637,000	-
Turn @ non signal	45,000	45,000	-
Evasive maneuver/maneuver	12,000	-	-
Evasive maneuver/no maneuver	45,000	-	-
Rollover	6,000	1,000	-
Noncollision - No impact	36,000	-	-
Object contacted/maneuver	66,000	5,000	-
Object contacted/no maneuver	82,000	7,000	76,000
Hit and run	3,000	-	-
Other - Rear-end	1,000	1,000	-
Other - Sideswipe	2,000	2,000	-
Other - Turn Across Path	1,000	1,000	-
Other - Turn Into Path	1,000	1,000	-
Other	22,000	-	-
	5,595,000	4,503,000	844,000

Table D2. Target Light-Vehicle Crash Data for Combined V2V and V2I Systems as Primary Countermeasure

Pre-Crash Scenario	All Crashes	V2V & V2I	AV
No driver present	1,000	-	-
Vehicle failure	45,000	-	45,000
Control loss/vehicle action	89,000	89,000	-
Control loss/no vehicle action	414,000	414,000	-
Running red light	226,000	226,000	-
Running stop sign	42,000	42,000	-
Road edge departure/maneuver	54,000	9,000	-
Road edge departure/no maneuver	240,000	48,000	192,000
Road edge departure/backing	68,000	-	68,000
Animal/maneuver	15,000	-	15,000
Animal/no maneuver	285,000	-	285,000
Pedestrian/maneuver	19,000	8,000	11,000
Pedestrian/no maneuver	39,000	5,000	35,000
Cyclist/maneuver	20,000	-	20,000
Cyclist/no maneuver	27,000	-	27,000
Backing into vehicle	127,000	127,000	-
Turning/same direction	195,000	195,000	-
Parking/same direction	38,000	38,000	-
Changing lanes/same direction	329,000	329,000	-
Drifting/same lane	102,000	102,000	-
Opposite direction/maneuver	9,000	9,000	-
Opposite direction/no maneuver	102,000	102,000	-
Rear-end/striking maneuver	80,000	80,000	-
Rear-end/LVA	22,000	22,000	-
Rear-end/LVM	190,000	190,000	-
Rear-end/LVD	384,000	384,000	-
Rear-end/LVS	906,000	906,000	-
LTAP/OD @ signal	195,000	195,000	-
Turn right @ signal	29,000	29,000	-
LTAP/OD @ non signal	178,000	178,000	-
SCP @ non signal	634,000	634,000	-
Turn @ non signal	43,000	43,000	-
Evasive maneuver/maneuver	12,000	-	-
Evasive maneuver/no maneuver	43,000	-	-
Rollover	3,000	1,000	-
Noncollision - No impact	30,000	-	-
Object contacted/maneuver	32,000	3,000	-
Object contacted/no maneuver	61,000	5,000	56,000
Hit and run	3,000	-	-
Other - Rear-end	1,000	1,000	-
Other - Sideswipe	2,000	2,000	-
Other - Turn Across Path	1,000	1,000	-
Other - Turn Into Path	1,000	1,000	-
Other	21,000	-	-
	5,356,000	4,417,000	754,000

Table D3. Target Heavy-Truck Crash Data for Combined V2V and V2I Systems as Primary Countermeasure

Pre-Crash Scenario	All Crashes	V2V & V2I	AV
No driver present	-	-	-
Vehicle failure	5,000	-	5,000
Control loss/vehicle action	5,000	5,000	-
Control loss/no vehicle action	16,000	16,000	-
Running red light	9,000	9,000	-
Running stop sign	2,000	2,000	-
Road edge departure/maneuver	14,000	1,000	-
Road edge departure/no maneuver	17,000	2,000	15,000
Road edge departure/backing	8,000	-	8,000
Animal/maneuver	2,000	-	2,000
Animal/no maneuver	5,000	-	5,000
Pedestrian/maneuver	1,000	-	-
Pedestrian/no maneuver	1,000	-	-
Cyclist/maneuver	-	-	-
Cyclist/no maneuver	-	-	-
Backing into vehicle	19,000	19,000	-
Turning/same direction	28,000	28,000	-
Parking/same direction	3,000	3,000	-
Changing lanes/same direction	49,000	49,000	-
Drifting/same lane	20,000	20,000	-
Opposite direction/maneuver	1,000	1,000	-
Opposite direction/no maneuver	13,000	13,000	-
Rear-end/striking maneuver	4,000	4,000	-
Rear-end/LVA	1,000	1,000	-
Rear-end/LVM	13,000	13,000	-
Rear-end/LVD	17,000	17,000	-
Rear-end/LVS	29,000	29,000	-
LTAP/OD @ signal	5,000	5,000	-
Turn right @ signal	3,000	3,000	-
LTAP/OD @ non signal	5,000	5,000	-
SCP @ non signal	22,000	22,000	-
Turn @ non signal	5,000	5,000	-
Evasive maneuver/maneuver	1,000	-	-
Evasive maneuver/no maneuver	3,000	-	-
Rollover	1,000	-	-
Noncollision - No impact	11,000	-	-
Object contacted/maneuver	19,000	1,000	-
Object contacted/no maneuver	17,000	1,000	16,000
Hit and run	1,000	-	-
Other - Rear-end	-	-	-
Other - Sideswipe	-	-	-
Other - Turn Across Path	-	-	-
Other - Turn Into Path	-	-	-
Other	3,000	-	-
	375,000	272,000	52,000

DOT HS 811 381
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Appendix III. National Highway Traffic Safety Administration, DOT HS 811 753, *Traffic Safety Facts: 2011 Data* (2013).

TRAFFIC SAFETY FACTS
2011 Data

DOT HS 811 753

April 2013

Overview

Motor vehicle travel is the primary means of transportation in the United States, providing an unprecedented degree of mobility. Yet for all its advantages, motor vehicle crashes are the leading cause of death for age 4 and every age 11 through 27 (based on 2009 data). The mission of the National Highway Traffic Safety Administration is to reduce deaths, injuries, and economic losses from motor vehicle crashes.

In 2011, 32,367 people were killed in the estimated 5,338,000 police-reported motor vehicle traffic crashes; 2,217,000 people were injured; and 3,778,000 crashes resulted in property damage only. Compared to 2010, this is a 2-percent decrease in the number of fatalities, and a 1.5-percent decrease in the number of police-reported motor vehicle traffic crashes, a 1-percent decrease in the number of people injured, and a 2-percent decrease in crashes resulting in property damage.

An average of 89 people died each day in motor vehicle crashes in 2011—one every 16 minutes.

Fortunately, much progress has been made in reducing the number of deaths and injuries on our Nation's highways. In 2011, the fatality rate per 100 million vehicle miles of travel (VMT) fell to an historic low of 1.10. The 2002 rate was 1.51 per 100 million VMT. The National Occupant Protection Use Survey (NOPUS) reported an 84-percent seat belt use rate nationwide for 2011. Data show a decrease in the number of fatalities in alcohol- impaired-driving crashes—from 13,472 in 2002 to 9,878 in 2011. Fatalities in alcohol-impaired- driving crashes when compared to the previous year (2010) decreased by 2.5 percent from 10,136 to 9,878.

This overview fact sheet contains statistics on motor vehicle fatalities based on data from the Fatality Analysis Reporting System (FARS). FARS is a census of fatal crashes within the 50 States, the District of Columbia, and Puerto Rico (although Puerto Rico is not included in U.S. totals). Crash and injury statistics are based on data from the National Automotive Sampling System General Estimates System (GES). GES is a probability-based sample of police-reported crashes, from 60 locations across the country, from which estimates of national totals for injury and property-damage-only crashes are derived.

The following terms will be used to define motorcycle occupants: a motorcycle rider is the operator only; a passenger is any person seated on the motorcycle but not in control of the motorcycle; and any combined reference to the "motorcycle rider" (operator) as well as the "passenger" will be referred to as motorcyclists. NHTSA publications prior to 2007 may not reflect this terminology.

In 2011, there were an estimated 5,338,000 police-reported traffic crashes, in which 32,367 people were killed and 2,217,000 people were injured; 3,778,000 crashes resulted in property damage only.

An average of 89 people died each day in motor vehicle crashes in 2011—an average of one every 16 minutes.

Table 1
People Killed and Injured and Fatality and Injury Rates, 2002–2011

Year	Killed	Resident Population (Thousands)	Fatality Rate per 100,000 Population	Licensed Drivers (Thousands)	Fatality Rate per 100,000 Licensed Drivers	Registered Motor Vehicles (Thousands)	Fatality Rate per 100,000 Registered Vehicles	Vehicle Miles Traveled (Billions)	Fatality Rate per 100 Million VMT
					Killed				
2002	43,005	287,625	14.95	194,602	22.10	225,685	19.06	2,856	1.51
2003	42,884	290,108	14.78	196,166	21.86	230,633	18.59	2,890	1.48
2004	42,836	292,805	14.63	198,889	21.54	237,949	18.00	2,965	1.44
2005	43,510	295,517	14.72	200,549	21.70	245,628	17.71	2,989	1.46
2006	42,708	298,380	14.31	202,810	21.06	251,415	16.99	3,014	1.42
2007	41,259	301,231	13.70	205,742	20.05	257,472	16.02	3,031	1.36
2008	37,423	304,094	12.31	208,321	17.96	259,360	14.43	2,977	1.26
2009	33,883	306,772	11.05	209,618	16.16	258,958	13.08	2,957	1.15
2010	32,999	309,330	10.67	210,115	15.71	257,312	12.82	2,967	1.11
2011	32,367	311,592	10.39	211,875	15.28	257,512	12.57	2,946	1.10

Year	Injured	Resident Population (Thousands)	Injury Rate per 100,000 population	Licensed Drivers (Thousands)	Injury Rate per 100,000 Licensed Drivers	Registered Motor Vehicles (Thousands)	Injury Rate per 100,000 Registered Vehicles	Vehicle Miles Traveled (Billions)	Injury Rate per 100 Million VMT
					Injured				
2002	2,926,000	287,625	1,017	194,602	1,503	225,685	1,296	2,856	102
2003	2,889,000	290,108	996	196,166	1,473	230,633	1,252	2,890	100
2004	2,788,000	292,805	952	198,889	1,402	237,949	1,172	2,965	94
2005	2,699,000	295,517	913	200,549	1,346	245,628	1,099	2,989	90
2006	2,575,000	298,380	863	202,810	1,269	251,415	1,024	3,014	85
2007	2,491,000	301,231	827	205,742	1,211	257,472	967	3,031	82
2008	2,346,000	304,094	771	208,321	1,126	259,360	904	2,977	79
2009	2,217,000	306,772	723	209,618	1,058	258,958	856	2,957	75
2010	2,239,000	309,330	724	210,115	1,066	257,312	870	2,967	75
2011	2,217,000	311,592	711	211,875	1,046	257,512	861	2,946	75

Sources: Vehicle Miles of Travel and Licensed Drivers — Federal Highway Administration; Registered Vehicles — R.L. Polk & Co. and Federal Highway Administration; Population — U.S. Bureau of the Census.

The fatality rate per 100 million VMT in 2011 was 1.10, down from 1.11 in 2010. The fatality rate based on population, or registered vehicles also declined. The injury rate per 100 million VMT in 2011 was 75, same as in 2010. However, the injury rate based on population and registered vehicles declined from 2010. (See Table 1).

Vehicle occupants accounted for 69 percent and motorcyclists accounted for 14 percent of traffic fatalities in 2011. The remaining 16 percent were pedestrians, pedalcyclists, and other nonoccupants. Males accounted for 71 percent of all traffic fatalities, 70 percent of all pedestrian fatalities, and 85 percent of all pedalcyclist fatalities in 2011.

Table 2
Motor Vehicle Occupants, Motorcyclists, and Nonoccupants Killed and Injured, 2002–2011

Year	Occupants by Vehicle Type						Motorcyclist	Nonoccupants				Total
	Passenger Cars	Light Trucks	Large Trucks	Buses	Other/ Unknown	Total		Pedestrian	Pedalcyclist	Other/ Unknown	Total	
Killed												
2002	20,569	12,274	689	45	528	34,105	3,270	4,851	665	114	5,630	43,005
2003	19,725	12,546	726	41	589	33,627	3,714	4,774	629	140	5,543	42,884
2004	19,192	12,674	766	42	602	33,276	4,028	4,675	727	130	5,532	42,836
2005	18,512	13,037	804	58	659	33,070	4,576	4,892	786	186	5,864	43,510
2006	17,925	12,761	805	27	601	32,119	4,837	4,795	772	185	5,752	42,708
2007	16,614	12,458	805	36	614	30,527	5,174	4,699	701	158	5,558	41,259
2008	14,646	10,816	682	67	580	26,791	5,312	4,414	718	188	5,320	37,423
2009	13,135	10,312	499	26	554	24,526	4,469	4,109	628	151	4,888	33,883
2010	12,491	9,782	530	44	524	23,371	4,518	4,302	623	185	5,110	32,999
2011	11,981	9,272	635	54	506	22,448	4,612	4,432	677	198	5,307	32,367
Injured												
2002	1,805,000	879,000	26,000	19,000	6,000	2,735,000	65,000	71,000	48,000	7,000	126,000	2,926,000
2003	1,756,000	889,000	27,000	18,000	7,000	2,697,000	67,000	70,000	46,000	8,000	124,000	2,889,000
2004	1,643,000	900,000	27,000	16,000	7,000	2,594,000	76,000	68,000	41,000	9,000	118,000	2,788,000
2005	1,573,000	872,000	27,000	11,000	10,000	2,494,000	87,000	64,000	45,000	8,000	118,000	2,699,000
2006	1,475,000	857,000	23,000	10,000	11,000	2,375,000	88,000	61,000	44,000	7,000	112,000	2,575,000
2007	1,379,000	841,000	23,000	12,000	8,000	2,264,000	103,000	70,000	43,000	10,000	124,000	2,491,000
2008	1,304,000	768,000	23,000	15,000	9,000	2,120,000	96,000	69,000	52,000	9,000	130,000	2,346,000
2009	1,216,000	759,000	17,000	12,000	7,000	2,011,000	90,000	59,000	51,000	7,000	116,000	2,217,000
2010	1,253,000	733,000	20,000	17,000	5,000	2,027,000	82,000	70,000	52,000	8,000	130,000	2,239,000
2011	1,240,000	728,000	23,000	13,000	6,000	2,010,000	81,000	69,000	48,000	9,000	126,000	2,217,000

Occupant Protection

In 2011, 49 States and the District of Columbia had seat belt use laws in effect. Use rates vary widely from State to State, reflecting factors such as differences in public attitudes, enforcement practices, legal provisions, and public information and education programs.

From 1975 through 2011, NHTSA estimates that seat belts saved the lives of 292,471 passenger vehicle occupants age 5 and older, including 11,949 lives saved in 2011. If all passenger vehicle occupants age 5 and older wore seat belts, an estimated 15,333 lives (that is, an additional 3,384) would have been saved in 2011.

In 2011, it is estimated that 263 children under age 5 were saved as a result of child restraint use, which includes child safety seats and seat belts. Among children, an estimated 9,874 lives were saved by restraints from 1975 through 2011.

NHTSA estimates that 11,949 lives were saved in 2011 by the use of seat belts.

In 2011, 29 percent of passenger car occupants and 33 percent of light-truck occupants involved in fatal crashes were unrestrained.

In fatal crashes, 77 percent of passenger vehicle occupants who were totally ejected from vehicles were killed. Seat belts are effective in preventing total ejections: only 1 percent of the occupants reported to have been using restraints were totally ejected, compared with 31 percent of the unrestrained occupants.

Table 3 shows belt use for passenger vehicle occupants in fatal crashes for 2011 compared to belt use in 2002.

Important Safety Information

Children in rear-facing child safety seats should not be placed in the front seat of cars equipped with passenger-side frontal air bags. The impact of a deploying air bag striking a rear-facing child safety seat could result in injury to the child. NHTSA also recommends that children age 12 and under sit in the rear seat away from the force of a deploying frontal air bag.

Table 3
Restraint Use Rates for Passenger Vehicle Occupants in Fatal Crashes, 2002 and 2011

Type of Occupant	Restraint Use Rate (Percent)	
	2002	2011
Drivers	62	70
All Passengers	56	66
Front Seat	62	72
Rear Seat	53	64
4 Years Old and Younger	78	87
5 Years Old and Older	54	64
All Occupants	60	69

Alcohol

Drivers are considered to be alcohol-impaired when their blood alcohol concentration (BAC) is .08 grams per deciliter (g/dL) or higher. Thus, any fatality occurring in a crash involving a driver with a BAC of .08 or higher is considered to be an alcohol-impaired-driving fatality. The term "driver" refers to the operator of any motor vehicle, including a motorcycle.

In 2011, there were 9,878 alcohol-impaired-driving fatalities. This is a decrease of 2.5 percent compared to 2010 (10,136), and it represents an average of one alcohol-impaired-driving fatality every 53 minutes.

The 9,878 alcohol-impaired-driving fatalities in 2011 (31% of total traffic fatalities) represent a 27-percent decrease from the 13,472 alcohol-impaired-driving fatalities reported in 2002 (31% of the total).

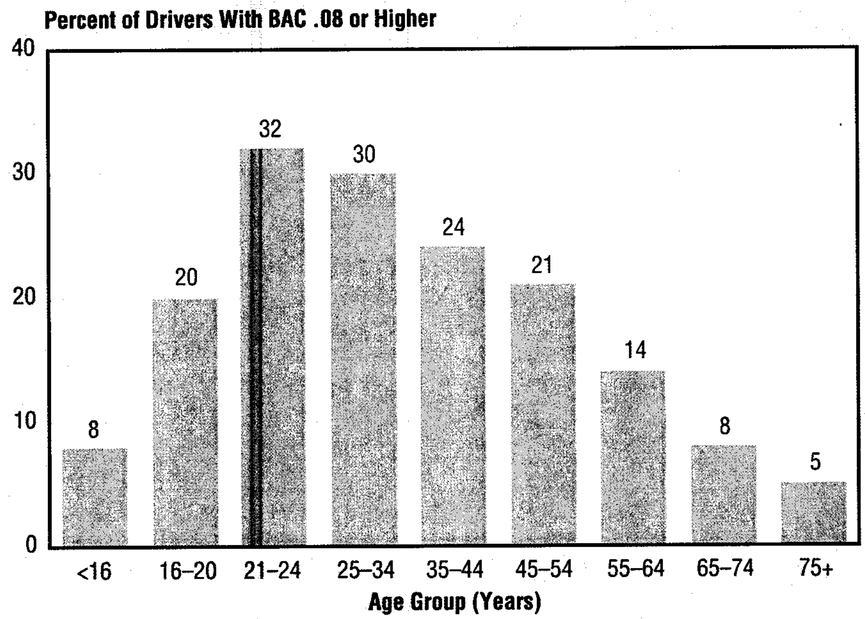
Alcohol-impaired-driving fatalities fell to 9,878 in 2011—31 percent of all traffic fatalities for the year.

Over 1.21 million drivers were arrested in 2011 for driving under the influence of alcohol or narcotics (FBI's Uniform Crime Report, 2011). This is an arrest rate of 1 for every 173 licensed drivers in the United States (based on 2010 figures).

In fatal crashes in 2011, 29 percent of motorcycle riders had a BAC level of .08 g/dL or higher, as compared with 24 percent for drivers of passenger cars, 21 percent for light-truck drivers, and 1 percent for drivers of large trucks.

In fatal crashes in 2011, the highest percentages of drivers with BAC levels of .08 g/dL or higher were recorded for drivers 21 to 24 years old (32%), followed by ages 25 to 34 (30%) and 35 to 44 (24%).

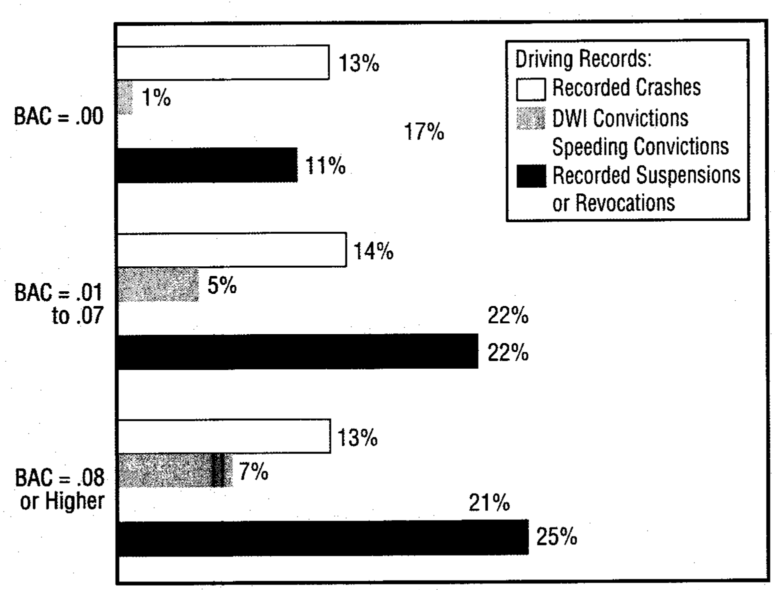
Figure 1
Drivers With BAC Levels of .08 or Higher Involved in Fatal Crashes by Age Group, 2011



The highest percentage of drivers in fatal crashes who had BAC levels of .08 g/dL or higher was for drivers 21 to 24 years old.

Drivers with a BAC of .08 g/dL or higher involved in fatal crashes were seven times more likely to have a prior conviction for driving while impaired (DWI) than were drivers with no alcohol (7% and 1%, respectively).

Figure 2
Previous Driving Records of Drivers Involved in Fatal Crashes by BAC, 2011



Drivers with a BAC level of .08 or higher in fatal crashes were seven times more likely to have a prior conviction for driving while impaired than were drivers with no alcohol.

Speeding

NHTSA considers a crash to be speeding-related if the driver was charged with a speeding-related offense or if an officer indicated that racing, driving too fast for conditions, or exceeding the posted speed limit was a contributing factor in the crash.

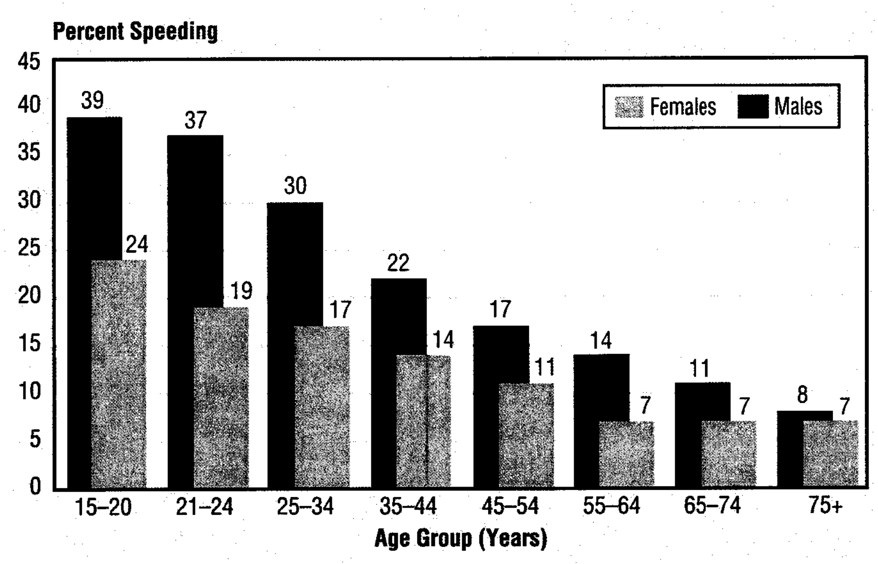
Table 4
Fatalities in Motor Vehicle Traffic Crashes by Speeding Involvement, 2002–2011

Year	Speeding		Not Speeding	
	Number	Percent	Number	Percent
2002	13,799	32	29,206	68
2003	13,499	31	29,385	69
2004	13,291	31	29,545	69
2005	13,583	31	29,927	69
2006	13,609	32	29,099	68
2007	13,140	32	28,119	68
2008	11,767	31	25,656	69
2009	10,664	31	23,219	69
2010	10,508	32	22,491	68
2011	9,944	31	22,423	69

Speeding is one of the most prevalent factors contributing to traffic crashes. In 2011, speeding was a contributing factor in 30 percent of all fatal crashes, and 9,944 (31 percent) lives were lost in speeding-related crashes (Table 4).

For drivers involved in fatal crashes, young males are the most likely to be speeding. In 2011, 39 percent of the 15- to 20-year-old and 37 percent of the 21- to 24-year-old male drivers who were involved in fatal crashes were speeding at the time of the crash. (Figure 3).

Figure 3
Speeding Drivers in Fatal Crashes by Age and Sex, 2011



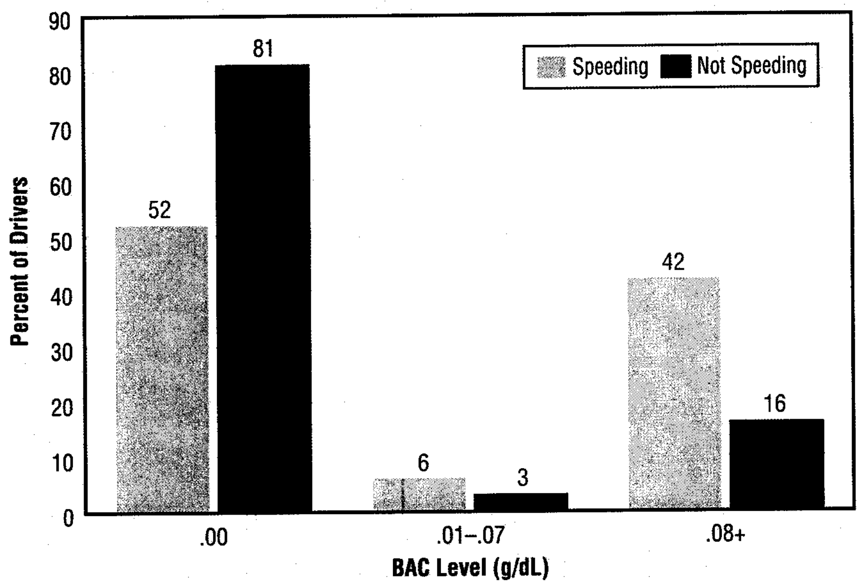
In 2011, 87 percent of speeding-related fatalities occurred on roads that were not Interstate highways.

Alcohol involvement was prevalent for drivers who were speeding in fatal crashes in 2011. Forty-two percent of the drivers who were speeding in fatal crashes in 2011 had BAC levels of .08 g/dL or higher, compared with only 16 percent for drivers who were not speeding.

In 2011, 87 percent of speeding-related fatalities occurred on roads that were not Interstate highways.

Figure 4

Percentage of All Drivers in Fatal Crashes by Speeding Involvement and BAC Level, 2011

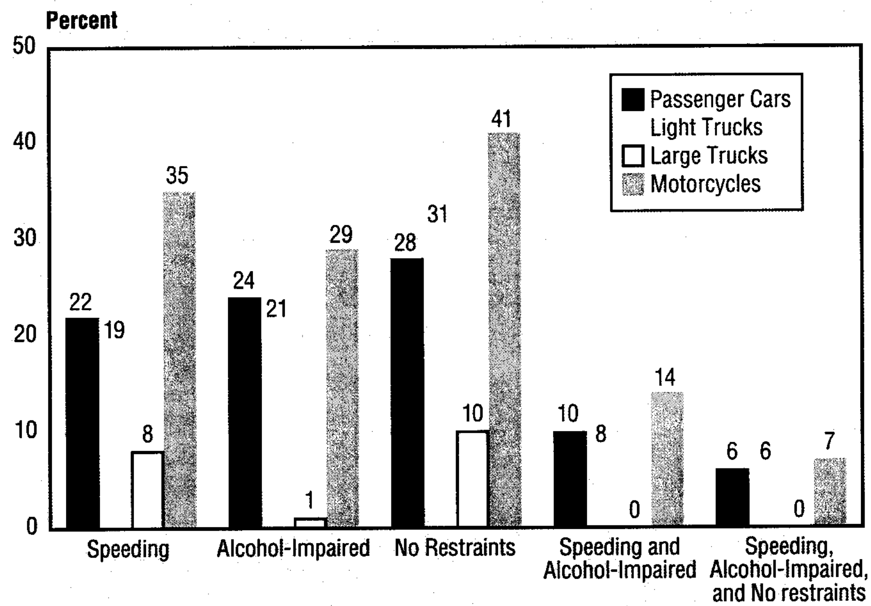


In fatal crashes, 35 percent of motorcycle riders were speeding.

In 2011, 35 percent of all motorcycle riders involved in fatal crashes were speeding, as compared to 22 percent for passenger car drivers, 19 percent for light-truck drivers, and 8 percent for large-truck drivers.

Figure 5

Speeding, Alcohol-Impaired, and Failure to Use Restraints Among Drivers Involved in Fatal Crashes by Vehicle Type, 2011



Note: Among large-truck drivers, speeding and alcohol-impairment; as well as speeding, alcohol-impairment, and failure to use restraints was less than 0.5 percent.

Motorcycles

Per vehicle mile traveled in 2011, motorcyclists were more than 30 times more likely than passenger car occupants to die in a motor vehicle traffic crash.

The 4,612 motorcyclist fatalities in 2011 accounted for 14 percent of all traffic fatalities for the year. An additional 81,000 motorcyclists were injured.

Per vehicle mile traveled in 2011, motorcyclists were more than 30 times more likely than passenger car occupants to die in a motor vehicle traffic crash and 5 times more likely to be injured.

In 2011, 40 percent of fatally injured motorcycle riders and 51 percent of fatally injured motorcycle passengers were not wearing helmets at the time of the crash.

More than one-fifth of motorcycle riders (22%) involved in fatal crashes in 2011 were driving the vehicles with invalid licenses at the time of the collision.

The percentage of motorcycle riders involved in fatal crashes in 2011 who had BAC levels of .08 g/dL or higher — 29 percent — was higher than for any other type of motor vehicle driver (as shown in Figure 5).

NHTSA estimates that helmets saved the lives of 1,617 motorcyclists in 2011. If all motorcyclists had worn helmets, an additional 703 lives could have been saved.

Large Trucks

In 2011, 12 percent (3,757) of all the motor vehicle traffic fatalities involved large trucks (gross vehicle weight rating greater than 10,000 pounds).

Of the fatalities that resulted from crashes involving large trucks, 72 percent were occupants of other vehicles, 17 percent were occupants of large trucks, and 11 percent were nonoccupants.

Twelve percent of all motor vehicle traffic fatalities in 2011 involved large trucks.

Table 5
Persons Killed and Injured in Crashes Involving Large Trucks, 2011

		Number	Percentage of Total
Killed	Occupants of Large Trucks	635	17
	in Single-Vehicle Crashes	*403*	*11*
	in Multiple-Vehicle Crashes	*232*	*6*
	Occupants of Other Vehicles in Crashes Involving Large Trucks	2,695	72
	Nonoccupants (Pedestrians, Pedalcyclists, etc.)	427	11
	Total	**3,757**	**100**
Injured	Occupants of Large Trucks	23,000	26
	in Single-Vehicle Crashes	*7,000*	*8*
	in Multiple-Vehicle Crashes	*15,000*	*17*
	Occupants of Other Vehicles in Crashes Involving Large Trucks	64,000	72
	Nonoccupants (Pedestrians, Pedalcyclists, etc.)	2,000	2
	Total	**88,000**	**100**

Large trucks accounted for 8 percent of all vehicles involved in fatal crashes and 3 percent of all vehicles involved in injury and property-damage-only crashes in 2011.

More than two-thirds (70%) of the large trucks involved in fatal crashes in 2011 collided with other motor vehicles in transport.

Twenty-six percent of all passenger vehicle occupants killed were ejected from the vehicle.

Passenger Vehicles

In 2011, 21,253 passenger vehicle occupants were fatally injured, accounting for 79 percent of all occupant fatalities (passenger cars 44%, light trucks 34%). Light trucks consist of SUVs, pickups, and vans. An additional 1,968,000 passenger vehicle occupants were injured, representing 94 percent of all occupants injured (passenger cars 59%, light trucks 35%). The average age of passenger vehicle occupant killed in crashes in 2011 was 42.

In 2011, 51 percent of passenger vehicle occupant fatalities occurred in vehicles that sustained frontal damage.

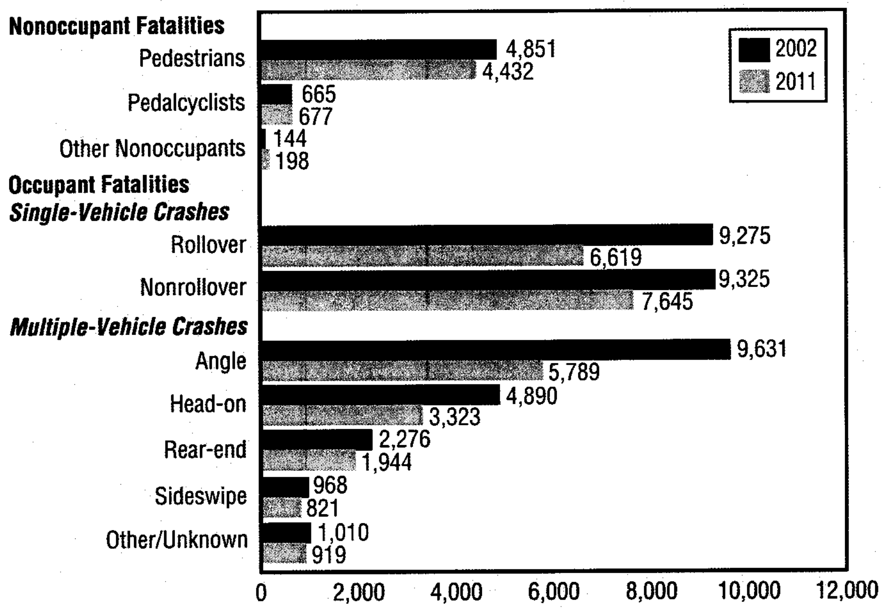
Ejection from the vehicle accounted for 26 percent of all passenger vehicle occupant fatalities. The ejection rate for occupants of passenger cars in fatal crashes was 19 percent and for light trucks was 35 percent.

Fifty-two percent of the passenger vehicle occupants killed in traffic crashes in 2011 were unrestrained.

More than half (52%) of the passenger vehicle occupants killed in traffic crashes in 2011 were unrestrained.

SUVs had the highest rollover involvement rate of any vehicle type in fatal crashes — 31 percent, as compared with 26 percent for pickups, 17 percent for vans, and 15 percent for passenger cars.

Figure 6
Fatalities in Traffic Crashes, 2002 and 2011



Older Population

In 2011, older people (65+) made up 17 percent of all traffic fatalities and 19 percent of all pedestrian fatalities.

In 2011, 13 percent (41.4 million) of the total U.S. resident population were people age 65 and older. There were 35 million licensed older drivers in 2011, accounting for 16 percent of the total licensed drivers in 2011.

In 2011, 5,401 older individuals (65+) were killed and 185,000 were injured in traffic crashes, accounting for 17 percent of all people killed and 8 percent of all the people injured in traffic crashes during the year. Older individuals made up 16 percent of all vehicle occupant fatalities, and 19 percent of all pedestrian fatalities.

The percentage of older drivers involved in fatal crashes in 2011 who had BAC levels of .08 g/dL or higher (6%) was lower than for any other group of adult drivers.

Fatalities in crashes involving older drivers decreased by 3 percent, from 5,782 in 2010 to 5,619 in 2011. Most traffic fatalities involving older drivers in 2011 occurred during the daytime (77%).

Young Drivers

In 2011, 4,347 young drivers ages 15 to 20 years old were involved in fatal crashes — a 48-percent decrease from the 8,325 involved in 2002. Driver fatalities for this age group decreased by 48 percent between 2002 and 2011.

In 2011, 10 percent of all the drivers involved in fatal crashes were between 15 and 20 years old.

There were 211.9 million licensed drivers in the United States in 2011, and young drivers accounted for 6 percent (12.6 million) of the total. Of all (43,668) drivers involved in fatal crashes, 10 percent (4,347) were young drivers, and of all (9,390,000) drivers involved in police-reported crashes, 13 percent (1,229,000) were young drivers.

In 2011, 32 percent of the young drivers who were killed in crashes had a BAC of .01 g/dL or higher; 26 percent had a BAC of .08 g/dL or higher.

Drivers are less likely to use restraints when they have been drinking. In 2011, 57 percent of the young drivers of passenger vehicles involved in fatal crashes who had been drinking were unrestrained. Of the young drivers who had been drinking and were killed in crashes, 70 percent were unrestrained. In comparison, of the non-drinking young drivers killed, 49 percent were unrestrained.

Children

In 2011, of the 32,367 traffic fatalities in the United States, the 14-and-younger age group accounted for 4 percent (1,140). This age group accounted for 3 percent (822) of all vehicle occupant fatalities, 8 percent (171,000) of all the people injured in motor vehicle crashes, and 7 percent (151,000) of all the vehicle occupants injured in crashes. During 2011, fatalities in this age group (1,140) decreased 6 percent from the 1,211 fatalities in 2010.

Nearly one-fifth (18%) of all children between the ages of 5 and 9 who were killed in motor vehicle traffic crashes were pedestrians. Among fatalities in children age14 and younger, pedestrian fatalities accounted for 20 percent in 2011.

In 2011, a total of 1,140 children age 14 and younger were killed in motor vehicle traffic crashes. Of those 1,140 fatalities, 181 (16%) occurred in alcohol- impaired driving crashes. Out of those 181 deaths, 91 (50%) were occupants of a vehicle with a driver who had a BAC level of .08 g/dL or higher. Another 25 children were pedestrians or pedalcyclists who were struck by drivers with a BAC of .08 g/dL or higher.

Pedestrian fatalities in 2011 were 9 percent lower than in 2002.

Pedestrians

In 2011, 4,432 pedestrians were killed and 69,000 were injured in traffic crashes in the United States, representing 14 percent of all fatalities and 3 percent of all people injured in traffic crashes.

On average, a pedestrian is killed in a motor vehicle crash every 119 minutes, and one is injured every 8 minutes.

Alcohol involvement — either for the driver or the pedestrian — was reported in 48 percent of the traffic crashes that resulted in pedestrian fatalities. Of the pedestrians involved, 35 percent had BAC levels of .08 g/dL or higher. Of the drivers involved in these fatal crashes, only 13 percent had BAC levels of .08 g/dL or higher. In 6 percent of the crashes, both the driver and the pedestrian had BAC levels of .08 g/dL or higher.

Nine percent of the pedalcyclists killed in traffic crashes in 2011 were between 5 and 15 years old.

Pedalcyclists

In 2011, 677 pedalcyclists were killed and an additional 48,000 were injured in traffic crashes. Pedalcyclists made up 2 percent of all traffic fatalities and 2 percent of all the people injured in traffic crashes during the year.

Most of the pedalcyclists killed or injured in 2011 were males (85% and 78%, respectively).

During 2011, 9 percent of the pedalcyclists killed in traffic crashes were between the ages of 5 and 15.

Table 6
Nonoccupant Traffic Fatalities, 2002–2011

Year	Pedestrian	Pedalcyclist	Other/Unknown Nonoccupants	Total
2002	4,851	665	114	5,630
2003	4,774	629	140	5,543
2004	4,675	727	130	5,532
2005	4,892	786	186	5,864
2006	4,795	772	185	5,752
2007	4,699	701	158	5,558
2008	4,414	718	188	5,320
2009	4,109	628	151	4,888
2010	4,302	623	185	5,110
2011	4,432	677	198	5,307

For more information:

Information on traffic fatalities is available from the National Center for Statistics and Analysis (NCSA), NVS-424, 1200 New Jersey Avenue SE., Washington, DC 20590. NCSA can be contacted at 800-934-8517 or via the following e-mail address: ncsaweb@dot.gov. General information on highway traffic safety can be accessed by Internet users at www.nhtsa.gov/NCSA. To report a safety-related problem or to inquire about motor vehicle safety information, contact the Vehicle Safety Hotline at 888-327-4236.

Other fact sheets available from the National Center for Statistics and Analysis are *Alcohol-Impaired Driving, Bicyclists and Other Cyclists, Children, Large Trucks, Motorcycles, Occupant Protection, Older Population, Passenger Vehicles, Pedestrians, Race and Ethnicity, Rural/Urban Comparisons, School Transportation-Related Crashes, Speeding, State Alcohol Estimates, State Traffic Data,* and *Young Drivers.* Detailed data on motor vehicle traffic crashes are published annually in *Traffic Safety Facts: A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System.* The fact sheets and annual Traffic Safety Facts report can be accessed online at www-nrd.nhtsa.dot.gov/CATS/index.aspx.

U.S. Department of Transportation
National Highway Traffic Safety Administration

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Appendix IV. U.S. Government Accountability Office, *Intelligent Transportation Systems: Vehicle-to-Infrastructure Technologies Expected to Offer Benefits, but Deployment Challenges Exist*, GAO-15-775 (Sept. 2015) ("GAO 2015 Report").

United States Government Accountability Office

Report to Congressional Requesters

September 2015

INTELLIGENT TRANSPORTATION SYSTEMS

Vehicle-to-Infrastructure Technologies Expected to Offer Benefits, but Deployment Challenges Exist

GAO-15-775

GAO Highlights

Highlights of GAO-15-775, a report to congressional requesters

September 2015

INTELLIGENT TRANSPORTATION SYSTEMS

Vehicle-to-Infrastructure Technologies Expected to Offer Benefits, but Deployment Challenges Exist

Why GAO Did This Study

Over the past two decades, automobile crash-related fatality and injury rates have declined over 34 and 40 percent respectively, due in part to improvements in automobile safety. To further improve traffic safety and provide other transportation benefits, DOT is promoting the development of V2I technologies. Among other things, V2I technologies would allow roadside devices and vehicles to communicate and alert drivers of potential safety issues, such as if they are about to run a red light. GAO was asked to review V2I deployment.

This report addresses: (1) the status of V2I technologies; (2) challenges that could affect the deployment of V2I technologies, and DOT efforts to address these challenges; and (3) what is known about the potential benefits and costs of V2I technologies.

GAO reviewed documentation on V2I from DOT, automobile manufacturers, industry associations, and state and local agencies. In addition, GAO interviewed DOT, Federal Communication Commission (FCC), and National Telecommunications Information Administration (NTIA) officials. GAO also conducted structured interviews with 21 experts from a variety of subject areas related to V2I. The experts were chosen based on recommendations from the National Academy of Sciences and other factors.

DOT, NTIA, and the FCC reviewed a draft of this report. DOT and NTIA provided technical comments, which were incorporated as appropriate. FCC did not provide comments.

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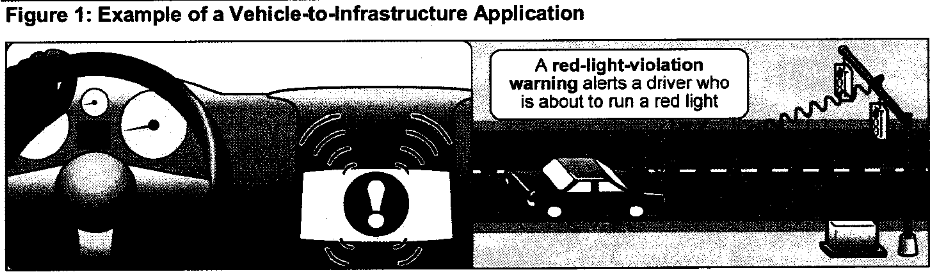
What GAO Found

Vehicle-to-infrastructure (V2I) technologies allow roadside devices to communicate with vehicles and warn drivers of safety issues; however, these technologies are still developing. According to the Department of Transportation (DOT), extensive deployment may occur over the next few decades. DOT, state, and local-transportation agencies; researchers; and private-sector stakeholders are developing and testing V2I technologies through test beds and pilot deployments. Over the next 5 years, DOT plans to provide up to $100 million through its Connected Vehicle pilot program for projects that will deploy V2I technologies in real-world settings. DOT and other stakeholders have also provided guidance to help state and local agencies pursue V2I deployments, since it will be up to these agencies to voluntarily deploy V2I technologies.

According to experts and industry stakeholders GAO interviewed, there are a variety of challenges that may affect the deployment of V2I technologies including: (1) ensuring that possible sharing with other wireless users of the radio-frequency spectrum used by V2I communications will not adversely affect V2I technologies' performance; (2) addressing states and local agencies' lack of resources to deploy and maintain V2I technologies; (3) developing technical standards to ensure interoperability; (4) developing and managing data security and addressing public perceptions related to privacy; (5) ensuring that drivers respond appropriately to V2I warnings; and (6) addressing the uncertainties related to potential liability issues posed by V2I. DOT is collaborating with the automotive industry and state transportation officials, among others, to identify potential solutions to these challenges.

The full extent of V2I technologies' benefits and costs is unclear because test deployments have been limited thus far; however, DOT has supported initial research into the potential benefits and costs. Experts GAO spoke to and research GAO reviewed indicate that V2I technologies could provide safety, mobility, environmental, and operational benefits, for example by: (1) alerting drivers to potential dangers, (2) allowing agencies to monitor and address congestion, and (3) providing driving and route advice. V2I costs will include the initial non-recurring costs to deploy the infrastructure and the recurring costs to operate and maintain the infrastructure. While some organizations have estimated the potential average costs for V2I deployments, actual costs will depend on a variety of factors, including where the technology is installed, and how much additional infrastructure is needed to support the V2I equipment.

Figure 1: Example of a Vehicle-to-Infrastructure Application



Source: GAO analysis of Department of Transportation documents. | GAO-15-775

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Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ANPRM	Advanced Notice of Proposed Rulemaking
CAMP	Crash Avoidance Metrics Partners, LLC
CO-Pilot	Cost Overview for Planning Ideas and Logical Organization Tool
DOT	U.S. Department of Transportation
DSRC	dedicated short-range communications
GHz	gigahertz
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
IEEE	Institute of Electrical and Electronics Engineers
ITS	intelligent transportation system
ITS America	Intelligent Transportation Society of America
ITS-JPO	Intelligent Transportation Systems-Joint Program Office
MHz	megahertz
MLIT	Ministry of Land, Infrastructure, Transport and Tourism (Japan)
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTIA	National Telecommunications and Information Administration
RSE	roadside equipment
RSU	roadside unit
SAE	Society for Automotive Engineers International
SCMS	Security Credential Management System
SPaT	Signal Phase and Timing
TMC	traffic management center
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
VICS	Vehicle Information and Communication System (Japan)

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September 15, 2015

The Honorable Barbara Comstock
Chairwoman
The Honorable Daniel Lipinski
Ranking Member
Subcommittee on Research and Technology
Committee on Science, Space, and Technology
House of Representatives

The Honorable Larry Bucshon
House of Representatives

Over the past two decades, automobile crash-related fatality and injury rates have declined nearly 34 percent and 40 percent, respectively, due in part to automobile safety features like safety belts and airbags.[1] The U.S. Department of Transportation (DOT) is working to further improve traffic safety through its connected vehicle research program, which aims to develop innovative technologies that enable vehicles, road infrastructure, and personal communications devices to wirelessly communicate and warn drivers and pedestrians of potential accidents. For example, DOT is collaborating with the automobile industry, academic institutions, technology firms, and state and local agencies to develop vehicle-to-infrastructure (V2I) technologies that allow vehicles to "communicate" with road infrastructure (such as traffic signals) through the wireless exchange of data. These technologies can enable the development of V2I software applications[2] that could, among other things: warn drivers of upcoming road conditions, such as work zones, or that they are approaching a curve at an unsafe speed; adjust traffic signal lights to provide priority to emergency vehicles or to address congestion; advise drivers about upcoming traffic and alternative routes; and provide driving advice to minimize stop-and-go driving.[3] For example, in 2011,

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[1]Department of Transportation (DOT) National Highway Traffic Safety Administration (NHTSA), *Traffic Safety Facts 2013*, DOT HS 812 139 (Washington, DC).

[2]A variety of software applications are being developed that would use V2I technologies to provide different types of information to drivers.

[3]These are just a few examples of V2I applications: DOT has defined over 40 potential applications that would serve a wide range of functions.

Japan implemented V2I through the deployment of the ITS Spot system. ITS Spot uses roadside equipment to collect and share data with vehicles in order to provide three basic services to drivers: dynamic route guidance, safe driving support, and electronic toll collection. Japan's extensive V2I network includes roughly 55,000 pieces of V2I equipment on local roads and 1,600 pieces of V2I equipment on its approximately 11,000 kilometers of expressways. Similarly, the Netherlands, Germany, and Austria are working to develop a European smart corridor that will provide drivers information on road work and upcoming traffic, among other things. Since V2I technologies are still in development in the United States and rely on the exchange of information between vehicles and infrastructure, developing and deploying V2I will require the collaboration of a number of stakeholders, particularly state and local agencies, as well as auto manufacturers.

In light of research showing the potential for V2I technologies to reduce traffic accidents and fatalities, as well as questions raised regarding potential technological and policy challenges, you asked us to review issues related to V2I technologies. We examined: (1) the status of V2I technologies; (2) the challenges, if any, that could affect the deployment of V2I technologies, and DOT efforts to address these challenges; and (3) what is known about the potential benefits and costs of V2I technologies. To address these issues, we reviewed documentation relevant to the V2I technology research efforts of DOT, state and local governments, and the automobile industry, including DOT's *2015 Federal Highway Administration (FHWA) V2I Draft Deployment Guidance and Products*[4] and the American Association of State Highway and Transportation Officials' (AASHTO) *National Connected Vehicle Field Infrastructure Footprint Analysis*. We interviewed officials from DOT's Office of the Assistant Secretary for Research and Technology, Intelligent Transportation Systems-Joint Program Office (ITS-JPO), FHWA, National Highway Traffic Safety Administration (NHTSA), and the Volpe National Transportation Systems Center about these efforts. In addition to DOT and its agencies, we also interviewed an additional 12 stakeholders that were involved in V2I efforts, such as associations representing state transportation agencies and engineers.[5] We interviewed officials at all

[4]DOT, *2015 FHWA Vehicle to Infrastructure Deployment Guidance and Products* (Draft), version 9 (September 9, 2014).

[5]We primarily selected stakeholders based on recommendations from DOT and industry associations.

seven V2I test beds located in Virginia, Michigan, Florida, Arizona, California, and New York.[6] We conducted site visits to three of the seven test beds—the Safety Pilot in Ann Arbor, Michigan, and the test beds in Southeast Michigan and Northern Virginia. We selected the three site visit locations based on which had the most advanced technology according to DOT and state officials. We used our interviews with stakeholders to help us understand the issues, and developed a structured set of questions for interviews with 21 experts, nine of whom were identified by the National Academy of Sciences. We selected an additional 12 experts based on the following factors: (1) their personal involvement in the deployment of V2I technologies; (2) recommendations from federal agencies and industry associations; and, (3) experts' involvement in a professional affiliation such as a V2I consortium or group dedicated to these technologies, or expertise on a specific challenge affecting V2I (e.g., privacy). The 21 experts we selected included domestic automobile manufacturers, V2I equipment suppliers, state and local government officials, privacy experts, global industry organizations responsible for developing technology standards, and academic researchers with relevant expertise. During these interviews we asked, among other things, for experts' views on the state of development and deployment of V2I technologies (including DOT's role in this process), the potential benefits of V2I technologies, and their potential costs.[7] In our report, we use the term "experts" to refer to the 21 selected individuals we interviewed using a structured set of questions; we use the term "stakeholders" to refer to those individuals we spoke with, but that were not interviewed using the structured set of questions. The viewpoints gathered through our expert interviews represent the viewpoints of these specific individuals and cannot be generalized to a broader population.

We also interviewed officials from the Federal Communications Commission (FCC) and National Telecommunications and Information Administration (NTIA) within the Department of Commerce regarding challenges related to the potential for spectrum sharing with V2I technologies. Finally, we conducted a site visit to Japan because of its years of experience with deployment and maintenance of its national V2I

[6]There are two test beds in Michigan, the Safety Pilot in Ann Arbor, Michigan, and one in Southeast Michigan, in Oakland County.

[7]In conducting our structured interviews, we used a standardized interview guide to ensure that we asked all of the experts the same questions.

system.[8] During our site visit, we interviewed Japanese government officials responsible for V2I and auto manufacturers on topics similar to those discussed with U.S. experts, including V2I deployment efforts, benefits, costs, and challenges. Information about Japan's V2I efforts provides an illustrative example from which to draw information on the potential benefits, costs, and challenges of deploying V2I technologies in the United States. Further details about our scope and methodology can be found in appendix I.

We conducted this performance audit from July 2014 to September 2015 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

DOT is working with the automobile industry, state and local transportation agencies, researchers, private sector stakeholders, and others to lead and fund research on connected vehicle technologies to enable safe wireless communications among vehicles, infrastructure, and travelers' personal communications devices.[9] Connected vehicle technologies include vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technologies:

- V2V technologies transmit data between vehicles to enable applications that can warn drivers about potential collisions.

[8]In the 1990s, Japan introduced its Vehicle Information and Communication System (VICS), which provides real-time road traffic information to drivers via a VICS-equipped navigation device. In 2011, Japan implemented V2I with its deployment of ITS Spot. In 2010, DOT and Japan's Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) signed a memorandum of cooperation to promote bilateral collaboration in the field of ITS.

[9]This effort is part of DOT's Intelligent Transportation Systems Program (ITS). ITS technologies consist of a range of communications, electronics, and computer technologies, such as systems that collect real-time traffic data and transmit information to the public via means such as dynamic message signs, ramp meters to improve the flow of traffic on freeways, and synchronized traffic signals that are adjusted in response to traffic conditions. From fiscal years 2003 through 2014, DOT provided about $570 million in funding for connected vehicle technologies. Funding for these efforts ranged from a low of $17 million in 2008 to a high of $84 million in 2011. These figures are not adjusted for inflation.

Specifically, V2V-equipped cars would emit data on their speed, position, heading, acceleration, size, brake status, and other data (referred to as the "basic safety message") 10 times per second to the on-board equipment of surrounding vehicles, which would interpret the data and provide warnings to the driver as needed. For example, drivers may receive a forward collision warning when their vehicle is close to colliding with the vehicle in front of them. V2V technologies have a greater range of detection than existing sensor-based crash avoidance technologies available in some new vehicles.[10] NHTSA is pursuing actions to require that vehicle manufacturers install the underlying V2V technologies that would enable V2V applications in new passenger cars and light truck vehicles, and requested comment on this issue in an August 2014 Advanced Notice of Proposed Rulemaking.[11] We reported on V2V technologies in November 2013.[12] Thus, we are not focusing on these technologies in this report.

- Vehicle-to-infrastructure (V2I) technologies transmit data between vehicles and the road infrastructure to enable a variety of safety, mobility, and environmental applications. V2I applications are designed to avoid or mitigate vehicle crashes, particularly those crash scenarios not addressed by V2V alone, as well as provide mobility and environmental benefits. Unlike V2V, DOT is not considering mandating the deployment of V2I technologies.

V2I applications rely on data sent between vehicles and infrastructure to provide alerts and advice to drivers. For example, the Spot Weather Impact Warning application is designed to detect unsafe weather conditions, such as ice or fog, and notify the driver if reduced speed or an alternative route is recommended (see left side of figure 1). DOT is also investigating the development of V2I mobility and environmental applications. For example, the Eco-Approach and Departure at Signalized Intersections application alerts drivers of the most eco-friendly speed for approaching and departing signalized intersections to minimize stop-and-

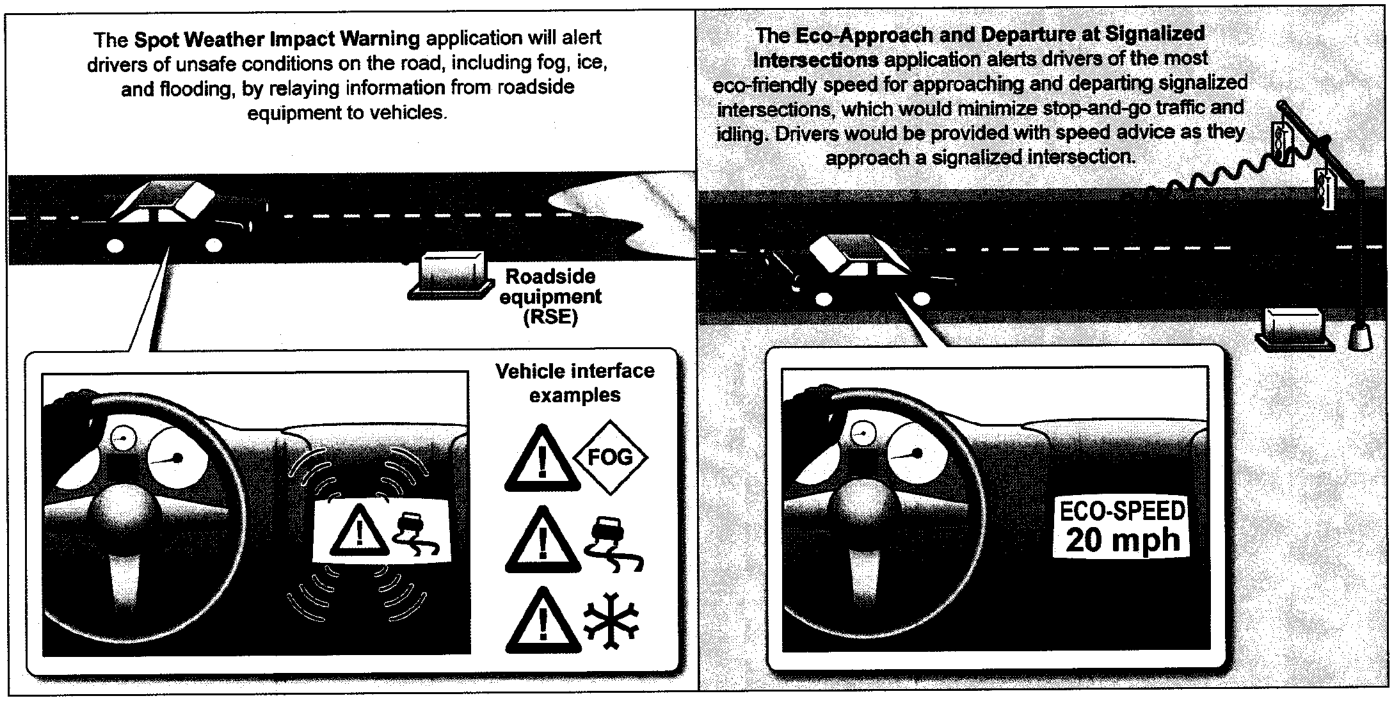
[10]For example, due to the sharing of data between vehicles, V2V technologies are capable of alerting drivers to potential collisions that are not visible to existing sensor-based technologies, such as a stopped vehicle blocked from view or a moving vehicle at a blind intersection. See GAO, *Intelligent Transportation Systems: Vehicle-to-Vehicle Technologies Expected to Offer Safety Benefits, but a Variety of Deployment Challenges Exist*, GAO-14-13 (Washington, D.C.: Nov. 1, 2013).

[11]79 Fed. Reg. 49270 (Aug. 20, 2014).

[12]GAO-14-13.

go traffic and idling (see right side of fig. 1), and eco-lanes, combined with eco-speed harmonization, (demonstrated in the following video) would provide speed limit advice to minimize congestion and maintain consistent speeds among vehicles in dedicated lanes.

Figure 1: Examples of Vehicle-to-Infrastructure Applications



Source: GAO analysis of Department of Transportation documents. | GAO-15-775

DOT is also pursuing the development of V2I mobility applications that are designed to provide traffic signal priority to certain types of vehicles, such as emergency responders or transit vehicles. In addition, other types of V2I mobility applications could capture data from vehicles and infrastructure (for example, data on current traffic volumes and speed) and relay real-time traffic data to transportation system managers and drivers. For example, after receiving data indicating vehicles on a particular roadway were not moving, transportation system managers could adjust traffic signals in response to the conditions, or alert drivers of alternative routes via dynamic message signs located along the roadway. In addition to receiving alerts via message signs, these applications could also allow drivers to receive warnings through on-board systems or personal devices. Japan has pursued this approach through its ITS Spot

V2I initiative, which uses roadside devices located along expressways to simultaneously collect data from vehicles to allow traffic managers to identify congestion, while also providing information to drivers regarding upcoming congestion and alternative routes.[13]

To communicate in a connected vehicle environment, vehicles and infrastructure must be equipped with dedicated short-range communications (DSRC), [14] a wireless technology that enables vehicles and infrastructure to transmit and receive messages over a range of about 300 meters (nearly 1,000 feet).[15] As previously noted, V2V-equipped cars emit data on their speed, position, heading, acceleration, size, brake status, and other data (referred to as the "basic safety message") 10 times per second to the surrounding vehicles and infrastructure. V2I-equipped infrastructure can also transmit data to vehicles, which can be used by on-board applications to issue appropriate warnings to the driver when needed. According to DOT, DSRC is considered critical for safety applications due to its low latency,[16] high reliability, and consistent availability. In addition, DSRC also transmits in a broadcast mode, providing data to all potential users at the same time. Stakeholders and federal agencies have noted that DSRC's ability to reliably transfer messages between infrastructure and rapidly moving vehicles is an essential component to detecting and preventing potential collisions. DSRC technology uses radiofrequency spectrum to wirelessly send and receive data.[17] The Federal Communications Commission

[13]Along expressways linking cities in Japan, ITS Spots are installed approximately every 10-15 kilometers and on inner-city expressways, ITS Spots are installed every 4 kilometers. An in-vehicle V2I application collects, stores, and uploads (via ITS Spot road infrastructure) an anonymous travel and behavior record of the vehicle, which contains information about the time, position, speed, acceleration, and angle of the vehicle.

[14]According to DOT, DSRC technology is the designated communications technology for communications-based active safety-systems research.

[15]DSRC is used for safety-critical applications that cannot tolerate interruption; however, DOT has noted that other technologies (such as cellular or satellite, among others) may be used for non-safety-critical applications.

[16]Latency refers to the relative response time in communications between the originating and the responding application components (onboard unit and/or roadside unit and/or back office services) needed for the application to be effective.

[17]Radio-frequency spectrum is a natural resource that is used to provide an array of wireless communications services critical to the U.S. economy and a variety of government functions.

(FCC), which manages spectrum for nonfederal users, including commercial, private, and state and local government users, allocated 75 megahertz (MHz) of spectrum—the 5.850 to 5.925 gigahertz (GHz) band (5.9 GHz band)[18]—for the primary purpose of improving transportation safety and adopted basic technical rules for DSRC operations.[19] However, in response to increased demands for spectrum,[20] FCC has requested comment on allowing other devices to "share" the 5.9 GHz band with DSRC technologies.[21]

V2I equipment may vary depending on the location and the type of application being used, although in general, V2I components in the connected vehicle environment include an array of roadside equipment (RSE) that transmits and receives messages with vehicles for the purpose of supporting V2I applications (see figure 2). For example, a V2I-equipped intersection would include:

[18]In the United States, responsibility for spectrum management is divided between two agencies: FCC and the Department of Commerce's National Telecommunications and Information Administration (NTIA). FCC manages spectrum use for nonfederal users, including commercial, private, and state and local government users and NTIA manages spectrum for federal government users and acts for the President with respect to spectrum management issues. Historically, concern about interference or crowding among users has been a driving force in the management of spectrum. In order to minimize interference, FCC and NTIA have allocated particular bands of spectrum for specific uses, and provided users with a license or authorization to use a specific portion of spectrum. According to NTIA, the FCC will issue the licenses for the non-federal DSRC systems. DOT's spectrum use is authorized by NTIA. 75 Fed. Reg. 38387 (July 1, 2010).

[19]Amendment of Parts 2 and 90 of the Commission's Rules to Allocate the 5.850-5925 GHz Band to the Mobile Service for Dedicated Short Range Communications of Intelligent Transportation Services, Report and Order, 14 FCC Rcd 18221 (1999)(*FCC 99-305*).

[20]As new spectrum-dependent technologies and services are brought to market and government users develop new mission needs, the demand for spectrum continues to increase and additional capacity will be needed to accommodate future growth that cannot be addressed through more efficient use of wireless technologies. One driver of the increased demand for spectrum has been the significant growth in commercial wireless broadband services, smart phones, and tablet computers. See GAO, *Spectrum Management: FCC's Licensing Approach in the 11, 18, and 23 Gigahertz Bands Currently Supports Spectrum Availability and Efficiency*, GAO-13-78R (Washington, D.C.: November 20, 2012).

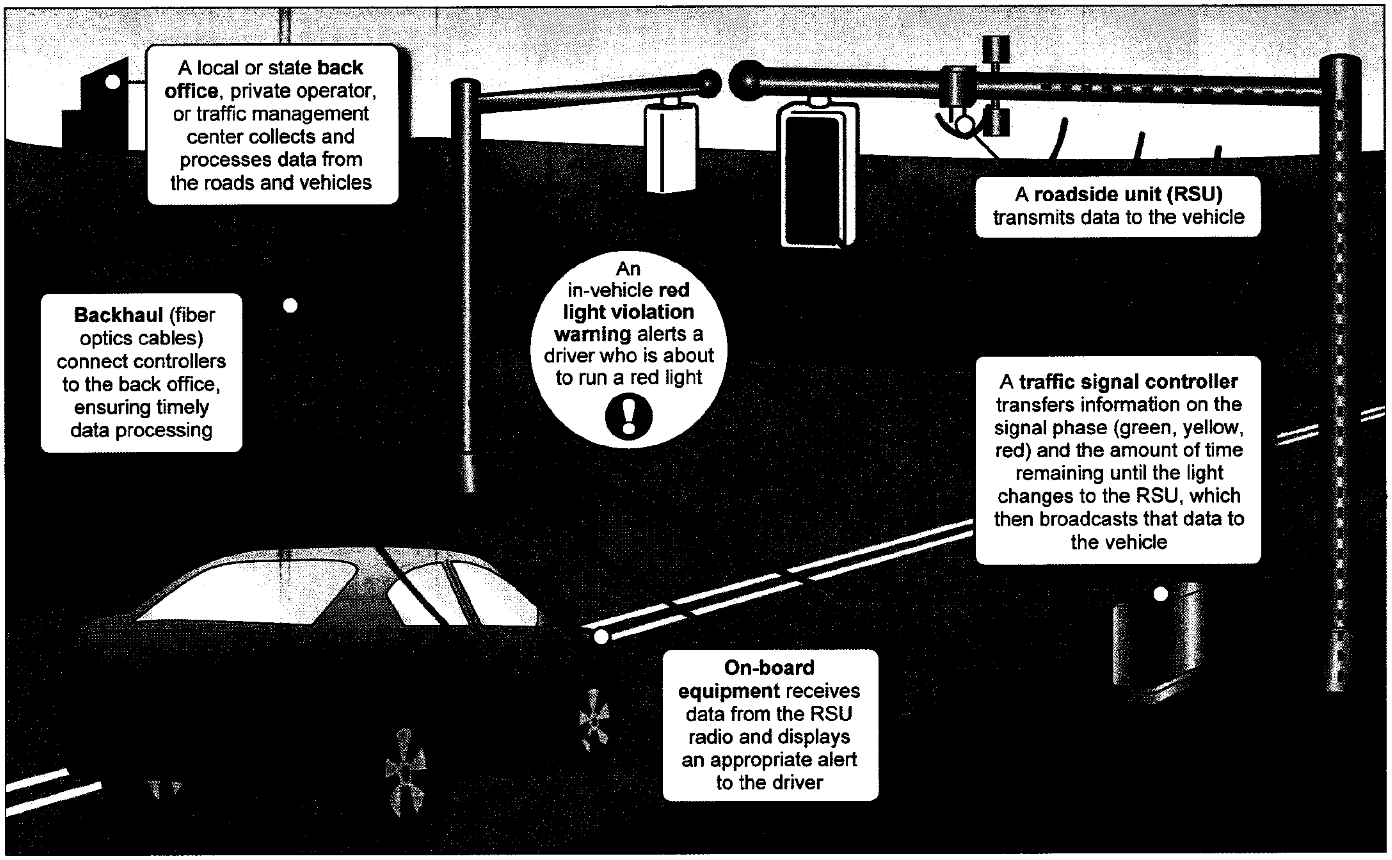
[21]In the Matter of Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band, *28 FCC Rcd 1769, (2014)*. The operator on an unlicensed device must accept whatever interference is received from the DSRC devices and must correct whatever interference is caused to DSRC devices. 47 C.F.R. § 15.5.

- Roadside units (RSU)—a device that operates from a fixed position and transmits data to vehicles. This typically refers to a DSRC radio,[22] which is used for safety-critical applications that cannot tolerate interruption, although DOT has noted that other technologies may be used for non-safety-critical applications.
- A traffic signal controller that generates the Signal Phase and Timing (SPaT) message, which includes the signal phase (green, yellow, and red) and the minimum and maximum allowable time remaining for the phase for each approach lane to an intersection. The controller transfers that information to the RSU, which broadcasts the message to vehicles.
- A local or state back office, private operator, or traffic management center that collects and processes aggregated data from the roads and vehicles. As previously noted, these traffic management centers may use aggregated data that is collected from vehicles (speed, location, and trajectory) and stripped of identifying information to gain insights into congestion and road conditions as well.[23]
- Communications links (such as fiber optic cables or wireless technologies) between roadside equipment and the local or state back office, private operator, or traffic management center. This is typically referred to as the "backhaul network."
- Support functions, such as underlying technologies and processes to ensure that the data being transmitted are secure.

[22]When referring to the DSRC radio alone, the term roadside unit (RSU) is used.

[23]Currently, state and local traffic-management centers gather and process traffic data, such as information on accidents and congestion, and take steps to respond to conditions, such as notifying emergency personnel, adjusting traffic signals, and providing alerts to drivers via roadway signs.

Figure 2: Example of Vehicle-to-Infrastructure Application Provided through Roadside Equipment



Source: GAO analysis of Department of Transportation documents. | GAO-15-775

V2I Deployment Efforts Are in the Early Stages and Extensive U.S. Deployment May Occur over the Next Few Decades

DOT and Various Stakeholders Are Developing and Testing V2I Technologies through Small Test Deployments

DOT, state and local transportation agencies, academic researchers, and private sector stakeholders are engaged in a number of efforts to develop and test V2I technologies and applications, as well as to develop the technology and systems that enable V2I applications. DOT's V2I work is funded through its connected vehicle research program. DOT's initial connected vehicle research focused on V2I technologies; however, it shifted its focus to V2V technologies because they are projected to produce the majority of connected vehicle safety benefits and they do not require the same level of infrastructure investment as V2I technologies. After conducting much of the research needed to inform its advanced notice of proposed rulemaking to require that vehicle manufacturers install V2V technologies in new passenger cars and light truck vehicles, DOT is now shifting its focus back to V2I technologies, and some of the technical work needed to develop V2V applications has also informed the development of V2I.[24] A number of DOT agencies are involved with the development and deployment of V2I technologies.[25] In addition, private companies have received contracts from DOT to develop the underlying concept of operations and technologies to support V2I applications, and auto manufacturers are collaborating with DOT in its efforts to develop

[24] 79 Fed. Reg. 49270 (Aug. 20, 2014).

[25] DOT's ITS-JPO is responsible for research execution and initial technology transfer activities, such as field testing. FHWA is coordinating with the states and developing the materials to support V2I deployment, such as guides, tools, and best practices—and is working to ensure that deployed services are geographically interoperable and that deployed services are developed in accordance with federal regulations. The Volpe National Transportation Systems Center provides technical support to ITS-JPO and FHWA, and conducts some laboratory testing for V2I technologies, as well as estimating safety benefits of connected vehicle technologies.

and pilot certain V2I applications and the underlying technologies to support them. State and local transportation agencies, which will ultimately be deploying V2I technologies on their roads, have also pursued efforts to test V2I technologies in real-world settings. However, to date, only small research deployments (such as those described below) have occurred to test V2I technologies:

- **The Safety Pilot Model Deployment:** DOT partnered with the University of Michigan Transportation Research Institute to collect data to help estimate the effectiveness of connected vehicle technologies and their benefits in real-world situations. The pilot was conducted in Ann Arbor, Michigan, from August 2012 to February 2014, and included roughly 2,800 V2V-equipped cars, trucks, and buses, as well as roadside V2I equipment placed at 21 intersections, three curve-warning areas, and five freeway sites. While the primary focus was on V2V technologies, the pilot also evaluated V2I technology, such as Signal Phase and Timing (SPaT) technologies. DOT officials stated that it would be releasing six reports with findings from the Safety Pilot in mid to late 2015, although these reports will primarily focus on V2V applications. As of July 2015, DOT has released one report that included an evaluation of how transit bus drivers responded to V2V and V2I warnings, and of how well the test applications performed in providing accurate warnings.[26] The two V2I applications included were a curve speed warning and a warning that alerts the bus driver if pedestrians are in the intended path of the bus when it is turning at an intersection.
- **Connected Vehicle Pooled Fund Study:** A group of state transportation agencies, with support from the FHWA, established the Connected Vehicle Pooled Fund Study.[27] The study aims to aid

[26]The report concluded that the transit safety applications have the potential to improve driver behavior and increase driver safety, but that improvements were needed to increase the accuracy of the warnings provided by the transit safety applications. For example, the report noted that the curve speed warning was provided early enough for the driver to take action only 57 percent of the time. U.S. Department of Transportation's Federal Highway Administration, *Independent Evaluation of the Transit Retrofit Package Safety Applications,* FHWA-JPO-14-175 (Washington, D.C.: February 2015).

[27]The primary members of the Connected Vehicle Pooled Fund Study include FHWA and transportation representatives from Virginia, California, Florida, Michigan, Minnesota, Maricopa County (Arizona), New Jersey, New York, Pennsylvania, Texas, Utah, Washington, and Wisconsin. Virginia serves as the lead state, with support from the University of Virginia.

transportation agencies in justifying and promoting the large scale deployment of a connected vehicle environment and applications through modeling, development, engineering, and planning activities. To achieve this goal, the study funds projects that facilitate the field demonstration, deployment, and evaluation of connected vehicle infrastructure and applications. For example, the University of Arizona and the University of California at Berkeley are collaborating on a project to develop and test an intelligent traffic-signal system that could, among other things, provide traffic signal priority for emergency and transit vehicles, and allow pedestrians to request for more time to cross the street.

- **Crash Avoidance Metrics Partners, LLC (CAMP):** CAMP—a partnership of auto manufacturers that works to accelerate the development and implementation of crash avoidance countermeasures—established a V2I Consortium that focuses on addressing the technical issues related to V2I. In 2013, DOT awarded a cooperative agreement to CAMP, with a total potential federal share of $45 million, to develop and test V2I safety, mobility, and environmental applications, as well as the underlying technology needed to support the applications, such as security and GPS-positioning technologies. According to an FHWA official, CAMP's current efforts include developing, testing, and validating up to five V2I safety applications, as well as a prototype for Cooperative Adaptive Cruise Control, an application that uses V2V and V2I technology to automatically maintain the speed of and space between vehicles. In addition to CAMP, automakers have established the Vehicle Infrastructure Integration Consortium, which coordinates with DOT on connected vehicle policy issues, such as interoperability of V2I technologies.
- **Test Beds**: DOT, state and local agencies, and universities have established connected vehicle test beds. Test beds provide environments (with equipped vehicles and V2I roadside equipment) that allow stakeholders to create, test, and refine connected vehicle technologies and applications. This includes DOT's Southeast Michigan Test Bed, which has been in operation since 2007 to provide a real-world setting for developers to test V2I and V2V concepts, applications, technology, and security systems. In addition, state agencies and universities have established their own test beds. For example, the University Transportation Center in Virginia, in collaboration with the Virginia Department of Transportation, established the Northern Virginia Test Bed to develop and test V2I applications, some of which target specific problems—like congestion—along the I-66 corridor. DOT offers guidance on how

research efforts can become DOT-affiliated test beds, with the goal of enabling test beds to share design information and lessons learned, as well as to create a common technical platform. According to DOT, there are over 70 affiliated test bed members. The deployment of connected vehicle infrastructure to date has been conducted in test beds in locations such as Arizona, California, Florida, Michigan, New York, and Virginia.[28] Additionally, officials from some of these test beds told us they may apply to the Connected Vehicle Pilot Deployment Program later this year (see below).

- **The Connected Vehicle Pilot Deployment Program:** Over the next 5 years, DOT plans to provide up to $100 million in funding for a number of pilot projects that are to design and deploy connected vehicle environments (comprised of various V2I and V2V technologies and applications) to address specific local needs related to safety, mobility, and the environment. As envisioned, there are to be multiple pilot sites with each site having different needs, purposes, and applications.[29] The program solicitation notes that successful elements of the pilot deployments are expected to become permanent operational fixtures in the real-world setting (rather than limited to particular testing facilities), with the goal of creating a foundation for expanded and enhanced connected vehicle deployments. FHWA solicited applications for the pilot program from January through March 2015. According to DOT, the initial set of pilot deployments (Wave 1 award) is expected to begin in Fall 2015, with a second set (Wave 2 award) scheduled to begin in 2017. Pilot deployments are expected to conclude in September 2020.

[28]In addition, the University of Michigan's Mobility Transformation Center is launching a test facility to research automated vehicle technologies, including V2I.

[29]DOT has provided examples of the types of V2I applications that can be included in the pilot projects, and has noted that the applications used will be influenced by what local need the project is trying to address. For example, a pilot project may be located in a rural area with extreme weather and may include applications that improve access to weather-related warnings and that improve safety at highway crossings. Another project may be located in an urban area with poor air quality and thus include applications that address congestion, pedestrian safety, and vehicular emissions in the downtown area.

DOT and Stakeholders Are Collaborating and Developing V2I Guidance for State and Local Agencies

DOT and other stakeholders have worked to provide guidance to help state and local agencies pursue V2I deployments, since it will be up to state and local transportation agencies to voluntarily deploy V2I technologies.[30] In September 2014, FHWA issued and requested comment on draft V2I deployment guidance intended to help transportation agencies make appropriate V2I investment and implementation decisions. For example, the guidance includes information on planning deployments, federal funding that can be used for V2I equipment and operations, technical requirements for equipment and systems, and applicable regulations, among other things. FHWA is updating the guidance and creating complementary guides, best practices, and toolkits, and officials told us they expect the revised guidance to be released by September 2015.[31] In addition, the American Association of State Highway and Transportation Officials (AASHTO),[32] in collaboration with a number of other groups, developed the *National Connected Vehicle Field Infrastructure Footprint Analysis*.[33] This report provides a variety of information and guidance for state and local agencies interested in V2I implementation, including a description of benefits; various state/local based scenarios for V2I deployments; underlying infrastructure and communications needs; timelines and activities for deployment; estimated costs and workforce requirements; and an identification of challenges that need to be addressed. AASHTO, with support the Institute of Transportation Engineers[34] and the Intelligent

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[30]As previously noted, unlike V2V, DOT is not considering mandating the deployment of V2I.

[31]For example, some of the tools FHWA is developing include a V2I Benefit Cost Analysis Tool; *V2I Planning Guide*; *Guide to V2I Cyber-Security*; *Guide to Licensing DSRC Roadside Units*; *Guide to V2I Communication Technology Selection*; V2I Message Lexicon (a list of allowable standard messages and formats for transmitted information for in-vehicle use); *Guide to Initial Deployments*; and Warrants for Deployment (a set of criteria which can be used to define the relative need for and appropriateness of a particular V2I application).

[32]AASHTO is a nonprofit association that serves as a liaison between state departments of transportation and the federal government.

[33]American Association of State Highway and Transportation Officials, *National Connected Vehicle Field Infrastructure Footprint Analysis* FHWA-JPO-14-125 (Washington, D.C.: June 2014).

[34]The Institute of Transportation Engineers is an international educational and scientific association of transportation professionals who are responsible for meeting mobility and safety needs.

Transportation Society of America,[35] is also leading a V2I Deployment Coalition. The Coalition has several proposed objectives: support implementation of FHWA V2I deployment guidance; establish connected vehicle deployment strategies, and support standards development. According to information from the coalition and DOT, the V2I Deployment Coalition will be supported by technical teams drawn from DOT, trade associations, transportation system owners/operators, and auto manufacturers.

Extensive Deployment of V2I Technologies May Occur over the Next Few Decades

While early pilot-project deployment of V2I technologies is occurring, V2I technologies are not likely to be extensively deployed in the United States for the next few decades. According to DOT, V2I technologies will likely be slowly deployed in the United States over a 20-year period as existing infrastructure systems are replaced or upgraded. DOT has developed a connected vehicle path to deployment that includes steps such as releasing the final version of FHWA's V2I deployment guidance for state and local transportation agencies (September 2015),[36] and awarding and evaluating the Connected Vehicle Pilot Deployment Program projects in two phases, with the first phase of awards occurring in September 2015 and evaluation occurring in 2019, and the second phase of awards occurring in September 2017 and evaluation occurring in 2021. In addition, DOT officials noted that V2I will capitalize on V2V, and its deployment will lag behind the V2V rulemaking. NHTSA will issue a final rule specifying whether and when manufacturers will be required to install V2V technologies in new passenger cars and light trucks.[37] In addition, FCC has not made a decision about whether spectrum used by DSRC can be shared with unlicensed devices, which could affect the time frames for V2I deployment. Even after V2I technologies and applications have been developed and evaluated through activities such as the pilot

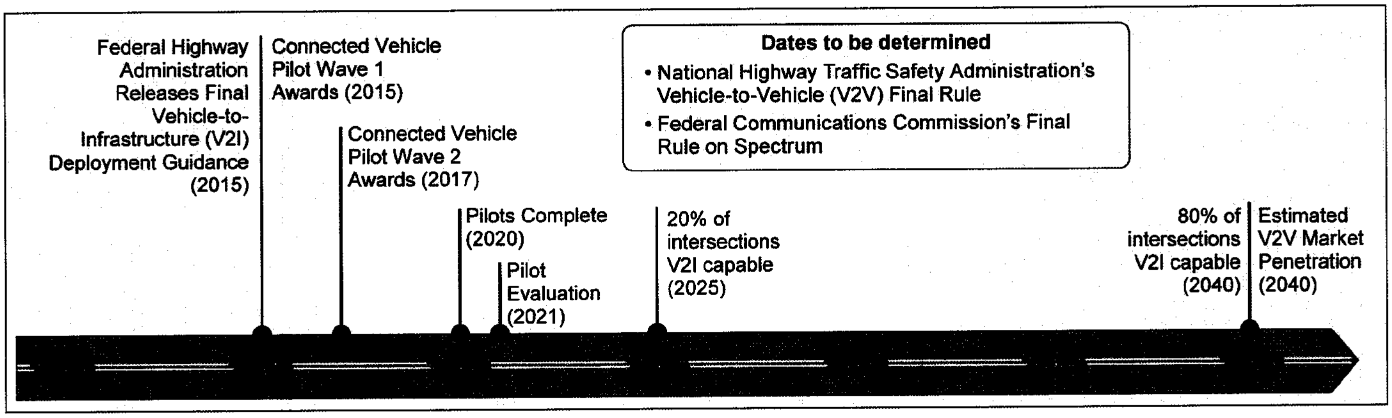
[35]The Intelligent Transportation Society of America (ITS America) is a national organization dedicated to advancing the research, development, and deployment of Intelligent Transportation Systems (ITS) to improve the nation's surface transportation system. Founded in 1991, ITS America's membership includes more than 450 public agencies, private sector companies, and academic and research institutions.

[36]DOT officials noted that this will be the final version of initial guidance, and that FHWA intends to update this guidance over time.

[37]Equipping cars with V2V technologies should allow them to receive V2I messages from roadside infrastructure; however, it is possible that stand-alone, after-market safety devices could be purchased to equip existing vehicles.

program, it will take time for state and local transportation agencies to deploy the infrastructure needed to provide V2I messages, and for drivers to purchase vehicles or equipment that can receive V2I messages. AASHTO estimated that 20 percent of signalized intersections will be V2I-capable by 2025, and 80 percent of signalized intersections would be V2I-capable by 2040. Similarly, AASHTO estimated that 90 percent of light vehicles would be V2V-equipped by 2040. However, DOT officials noted that environmental and mobility benefits can occur even without widespread market penetration and that other research has indicated certain intersections may be targeted for deployment. Similarly, in its *National Connected Vehicle Field Infrastructure Footprint Analysis*, AASHTO noted that early deployment of V2I technologies will likely occur at the highest-volume signalized intersections, which could potentially address 50 percent of intersection crashes.[38] See figure 3 for a list of planned events and milestones related to DOT's path to deployment of connected vehicle technologies.

Figure 3: DOT's Planned Connected Vehicle Path to Deployment, 2010-2040



Source: GAO analysis of Department of Transportation documents. | GAO-15-775

[38]AASHTO cited research from the March 2009 Noblis report, *Footprint Analysis for IntelliDrive^{SM} V2V Applications, Intersection Safety Applications, and Tolled Facilities*, which found that twenty percent of intersections in the three largest metro areas accounted for 50 percent of the collisions. However, the study does not directly address but only infers the safety benefits of V2I-enabling signalized intersections.

A Variety of Challenges, Including Potential Spectrum Sharing, May Affect the Deployment of V2I

According to experts and industry stakeholders we interviewed, there are a variety of challenges that may affect the deployment of V2I technologies including: (1) ensuring that possible sharing with other wireless users of the radiofrequency spectrum used by V2I communications will not adversely affect V2I technologies' performance; (2) addressing states' lack of resources to deploy and maintain V2I technologies; (3) developing technical standards to ensure interoperability between devices and infrastructure; (4) developing and managing a data security system and addressing public perceptions related to privacy; (5) ensuring that drivers respond appropriately to V2I warnings; and (6) addressing the uncertainties related to potential liability issues posed by V2I. DOT is collaborating with the automotive industry and state transportation officials, among others, to identify potential solutions to these challenges.

Potential Spectrum Sharing

As previously noted, V2I technologies depend on radiofrequency spectrum, which is a limited resource in high demand due in part to the increase in mobile broadband use. To address this issue, the current and past administrations, Congress, FCC, and others have proposed a variety of policy, economic, and technological solutions to support the growing needs of businesses and consumers for fixed and mobile broadband communications by providing access to additional spectrum.[39] One proposed solution, introduced in response to requirements in the Middle Class Tax Relief and Job Creation Act of 2012,[40] would allow unlicensed devices[41] to share the 5.9 GHz band radiofrequency spectrum that had been previously set aside for the use of DSRC-based ITS applications

[39]In a previous GAO report, we found that that the scarcity of spectrum in the United States is to some extent a result of the manner in which this resource has been allocated, managed, and used, rather than because of a physical scarcity of the resource. GAO, *Spectrum Management: Incentives, Opportunities, and Testing Needed to Enhance Spectrum*, GAO-13-7 (Washington, D.C.: November 2012).

[40]Pub. L. No. 112-96, §6406, 126 Stat. 156, 231.

[41]Traditional unlicensed equipment consists of low powered devices that operate in a limited geographic range, such as garage door openers and devices that offer wireless access to the Internet. They include Wi-Fi-enabled local area networks and fixed outdoor broadband transceivers used by wireless Internet service providers to connect devices to broadband networks.

such as V2I and V2V technologies.[42] FCC issued a Notice of Proposed Rulemaking in February 2013 that requested comments on this proposed solution.[43]

DOT officials and 17 out of 21 experts we interviewed considered the proposed spectrum sharing a significant challenge to deploying V2I technologies.[44] DSRC systems support safety applications that require the immediate transfer of data between entities (vehicle, infrastructure, or other platforms). According to DOT officials, delays in the transfer of such data due to harmful interference from unlicensed devices may jeopardize crash avoidance capabilities. Experts cited similar concerns, with one state official saying that if they deploy applications and they do not work due to harmful interference, potential users may not accept V2I. Seven experts we interviewed agreed that further testing was needed to determine if sharing would result in harmful interference to DSRC. In addition, DOT officials noted that changing to a shared 5.9 GHz band could impact current V2I research, which is based on the assumption that DSRC systems will have reliable access to the 5.9 GHz wireless spectrum.

According to Japanese government officials we interviewed, Japan also considered whether to share its dedicated spectrum with unlicensed devices and decided not to allow sharing of the spectrum used for V2I in the 700 MHz band.[45] According to officials we interviewed, Japan's Ministry of Internal Affairs and Communications conducted a study to test interference with V2I technologies and mobile phones to determine the

[42]Spectrum sharing can be defined as the cooperative use of common spectrum that allows disparate missions to be achieved. In this way, multiple users agree to access the same spectrum at different times or locations, as well as negotiate other technical parameters, to avoid adversely interfering with one another. For sharing to occur, users and regulators must negotiate and resolve where (geographic sharing), when (sharing in time), and how (technical parameters) spectrum will be used. GAO-13-7.

[43]In the Matter of Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band, Notice of Proposed Rulemaking, 28 FCC Rcd 1769 (2013).

[44]Two of 21 experts we interviewed did not provide a response to this question.

[45]In 2001, the Japanese government dedicated the 5.8GHz band to broadcast safety information using DSRC, and in 2011, dedicated the 700 MHz (760 MHz) band to support V2I technologies.

impact on reliability and latency in delivering safety messages.[46] Based on these tests, the Japanese government decided not to allow sharing of the spectrum band used for V2I, because sharing could lead to delays or harmful interference with V2I messages. Japanese auto manufacturers we interviewed in Japan supported the decision of the Japanese government to keep the 700 MHz band dedicated to transportation safety uses. According to officials, if latency problems affect the receipt of safety messages, this could degrade the public's trust, consequently slowing down acceptance of the V2I system in Japan.

Since the Notice of Proposed Rulemaking was announced, various organizations have begun efforts to evaluate potential spectrum sharing in the 5.9 GHz band and some have expressed concerns. For example, harmful interference from unlicensed devices sharing the same band could affect the speed at which a V2I message is delivered to a driver. NTIA, which has conducted a study on the subject, identified risks associated with allowing unlicensed devices to operate in the 5.9 GHz band, and concluded that further work was needed to determine whether and how the risks identified can be mitigated. DOT also plans to evaluate the potential for unlicensed device interference with DSRC as discussed below.[47]

Given the pending FCC rulemaking decision, DOT, technology firms, and car manufacturers have taken an active role pursuing solutions to spectrum sharing. Specifically, DOT's fiscal year 2016 budget request included funds for technical analysis to determine whether DSRC can co-exist with the operation of unlicensed wireless services in the same radiofrequency band without undermining safety applications.[48] According to DOT officials, since industry has not yet developed an unlicensed device capable of sharing the spectrum, the agency does not have a specific date for completion of this testing at this time. DOT officials

[46]In this case, latency refers to the relative response time in communications between the originating and the responding application components (onboard unit, roadside unit, or back office services) needed for the application to be effective.

[47]See Department of Commerce, NTIA. *Evaluation of the 5350-5470 MHz and 5850-5925 MHz Bands Pursuant to Section 6406(b) of the Middle Class Tax Relief and Job Creation Act of 2012* (Washington, D.C.: January 2013).

[48]DOT, *Fiscal Year 2016 Office of Secretary Congressional Budget Justification* (Washington, D.C.: February 2015).

noted, however, that they would work with NTIA in any spectrum-related matter to inform FCC of its testing results.[49] According to FCC officials we spoke with, FCC is currently collecting comments and data from government agencies, industry, and other interested parties and will use this information to inform their decision. For example, since 2013, representatives from Toyota, Denso, CSR Technology, and other firms worked together as part of the Institute of Electrical and Electronics Engineers (IEEE) DSRC Tiger Team[50] to evaluate potential options and technologies that would allow unlicensed devices to use the 5.9 GHz band without causing harmful interference to licensed devices. However, the representatives did not reach an agreement on a unified spectrum-sharing approach. Another ongoing effort from Cisco Systems, the Alliance of Automobile Manufacturers, and the Association of Global Automakers is preparing to test whether unlicensed devices using the "listen, detect and avoid"[51] protocol would be able to share spectrum without causing harmful interference to incumbent DSRC operations.[52] As of September 2015, FCC has not announced a date by which it will make a decision.

Lack of State and Local Resources to Develop and Maintain V2I Systems

Because the deployment of V2I technologies will not be mandatory, the decision to invest in these technologies will be up to the states and localities that choose to use them as part of their broader traffic-management efforts. However, many states and localities may lack resources for funding both V2I equipment and the personnel to install, operate, and maintain the technologies. In its report on the costs,

[49]NTIA works with FCC via the Policy and Plans Steering Group, as well as the Policy and Plans Steering Group Spectrum Working group, to foster dialogue between agencies. In addition to the Steering Group, DOT has submitted information through NTIA to the FCC as part of the public docket process.

[50]IEEE members are engineers, scientists, and allied professionals whose technical interests are rooted in electrical and computer sciences, engineering, and related disciplines.

[51]The unlicensed devices would be expected to detect and vacate bands that are being used by DSRC operations at that time.

[52]The tests are developmental in nature and designed to demonstrate and measure a Cisco proposal in the presence of DSRC transmitters and to ensure the technology operates as intended. Testing will begin in a laboratory setting and then advance to field tests, with the expectation that the initial round of feasibility testing will be completed by the end of 2015.

benefits, and challenges of V2I deployment by local transportation agencies, the National Cooperative Highway Research Program (NCHRP) noted that many states they interviewed said that their current state budgets are the leanest they have been in years.[53] Furthermore, states are affected because traditional funding sources, such as the Highway Trust Fund, are eroding, and funding is further complicated by the federal government's current financial condition and fiscal outlook.[54] Consequently, there can be less money for state highway programs that support construction, reconstruction, and improvement of highways and bridges on eligible federal-aid highway routes, as well as for other authorized purposes.[55] According to one stakeholder we interviewed, there have been widespread funding cuts for state DOTs, and many state DOTs must first focus on maintaining the infrastructure and equipment they already have before investing in advanced technologies.[56] Ten experts we interviewed, including six experts from state and local transportation agencies, agreed that the lack of state and local resources will be a significant challenge to deploying V2I technologies.[57] According to one report, without additional federal funding, deploying V2I systems would be difficult.[58]

Even if states decide to invest in V2I deployment, states and localities may face difficulties finding the resources necessary to operate and maintain V2I technologies. We have previously found that effectively

[53]The NCHRP is a research organization administered by the Transportation Research Board, and sponsored by members of AASHTO, in cooperation with FHWA. Individual projects are conducted by contractors with oversight provided by volunteer panels of expert stakeholders.

[54]See GAO. *High-Risk Series: An Update*, GAO-15-290 (Washington, D.C; February 2015). GAO maintains a program to focus attention on government operations that it identifies as high risk due to their greater vulnerabilities to fraud, waste, abuse, and mismanagement or the need for transformation to address economy, efficiency, or effectiveness challenges. Funding the nation's surface transportation system has been listed on our high-risk list since 2007.

[55]GAO, *Highway Trust Fund: All States Received More Funding Than They Contributed in Highway Taxes from 2005 to 2009,* GAO-11-918. (Washington. D.C: September 2011).

[56]The stakeholder was from a transportation research organization.

[57]Five of 21 experts we interviewed did not provide a response to this question.

[58]NCHRP, *Costs and Benefits of Public-Sector Deployment of Vehicle-to-Infrastructure Technologies, 03-101 (Washington, D.C.:* 2013).